CENTRAL STATION
ELECTRICITY SUPPLY

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AN INTRODUCTION TO THE STUDY OF

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PREFACE

Electric Lighting already possesses an extensive literature, and those who have been engaged as electrical engineers for many years are necessarily acquainted with the writings of a large number of well-known professional men. Very few attempts have been made, nevertheless, to include in one work the leading points peculiar to the inception and carrying on of a public supply of electricity under statutory powers in this country.

It has been said that books on engineering subjects are too often prepared by the wrong people, and that they therefore deal with things as it seems to the mind of the writer they should be, rather than as they are. A well-known writer has expressed the opinion that "the great fault in electrical books generally is that they are usually written by the wrong man. A book on electric lighting should be written by an experienced electric light engineer, not by some one who wants to found a reputation as an engineer on his book on the subject. Similarly a book on dynamos should be written by a designer of dynamos, and so on."

In the case of the present volume we hope that this fault does not apply. As engineers who have for

many years been connected with the business of central station management, and the design and maintenance of apparatus employed in general supply, we have thought that there is still room for a work dealing broadly with the subject.

Our intention has been to take up in a general way the points that arise in central station practice as distinct from electric lighting. A modern central station is a carefully thought out combination of engineering and electrical plant, and considering the number of different parts comprised in the equipment, and the varied forms given them to meet local conditions and individual tastes, it is evident that within the moderate dimensions of a single volume it is well-nigh impossible to exhaustively treat each one in detail. For this reason we have considered it unnecessary to include formulæ and tables which can be found in nearly all text-books and engineering and electrical pocket-books, while the mathematical treatment of electrical questions has already received such attention and been so fully developed elsewhere that we see no reason to add to this side of the subject, important as it undoubtedly is. In a work such as this the limitations of space forbid more than a discussion of general principles and a brief mention of the devices that can be introduced to meet the essential conditions of a safe, efficient, and economical generation and distribution of energy. We have, therefore, thought it desirable to give references to memoirs, papers, and articles wherein special points of importance are considered with some minuteness. Engineers cannot afford

to neglect the transactions of institutions and societies where subjects of interest to the profession are fully discussed, nor the large amount of useful matter which, from time to time, appears in the volumes of the technical press, and we therefore make no apology for drawing freely from these sources.

In this the second edition we have endeavoured to bring the treatment of the subject up-to-date, and, as far as it is practicable to do so, to meet the suggestions of our reviewers, but to conform to the requirements of all would result in defeating the object we had in view in publishing this work, and which is set forth above.

In all debatable matters we have endeavoured to avoid personal bias, and to give fairly and impartially the opinions of others, both for and against, leaving our readers to form their own conclusions. Whatever failings our production may possess, we leave it in the hands of the reader, with the full knowledge that it is at least an honest attempt to place before him the elements of Central Station Electricity Supply in a concise and convenient form.

A. G.
C. H. Y.

1906.

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CENTRAL STATION ELECTRICITY SUPPLY

CHAPTER I

INTRODUCTION

Historical.—From the year 1831, when Faraday made his important discovery of electro-magnetic induction and the possibility of transforming mechanical into electrical energy by its means, nearly fifty years elapsed before the dynamo became a commercial article and the possibility of electricity supply upon anything like a large scale was practically demonstrated. For a considerable time the machines made were magneto machines, permanent magnets alone being employed to produce the magnetic field, and until Pixii, in 1832, suggested a commutating device for the purpose of obtaining a direct current, these machines produced alternating currents only. In 1845 the use of electro-magnets was first adopted, the excitation being obtained from a separate source, and it was not until 1867 that the self-exciting dynamo was introduced as a result of the independent labours of Varley, Siemens, and Wheatstone.[1] The closed armature circuit and commutator as now used were intro-

[1] See S. A. Varley, *Elect. Review*, vol. xxi. p. 583, and vol. xxv. pp. 485-708; also "Classified Abstracts of Patents," *Journ. Soc. Tel. Eng.* 1879.

duced in 1864 by Pacinotti and were re-invented by Gramme in 1870, who, being an engineer, was the first to produce a really successful dynamo. The electric light from this time to 1878 was of a very crude character, and consisted of a dynamo and some form of clockwork arc lamp, each lamp being supplied independently from a separate dynamo. About 1878 Brush and others solved the problem of running a number of arc lamps from one dynamo, and from that time electric lighting has rapidly advanced. Companies were formed for the purpose of supplying and erecting dynamos and arc lamps in various works in the large industrial centres, as well as for show-purposes and for street lighting, and the building of dynamos and electrical apparatus on a commercial scale became a recognized industry. Companies were also formed for the purpose of supplying electricity to the public from a centre, and although this was at first chiefly confined to street lighting, it was very soon found that there was a demand for electricity on private premises, and as the companies' field of operations began gradually to extend in this direction, the foundation of the electricity supply business was laid.

Hitherto but little progress had been made with the incandescent lamp, and, although in 1841 Starr and King invented a lamp in which a light was produced by means of an incandescent filament, no adequate means were then available for producing a satisfactory vacuum, nor were the conditions necessary to insure success appreciated, with the inevitable result that it could not be practically developed.

Later, however, Swan, Edison, Lane-Fox and others, having at their disposal more efficient means of properly exhausting the lamp, and having an idea of the conditions

required, succeeded in obtaining a more satisfactory result, and very soon the incandescent lamp became a commercial article.

Competition with Gas.—Even before the success of the incandescent lamp was fully demonstrated, the gas companies viewed the new illuminant not only with disfavour but with evident uneasiness, and were not slow to recognize that it might in the near future become a dangerous rival. It was only natural that those interested in gas undertakings should do all in their power to prejudice the public against the use of electricity, and the wildest rumours were circulated with respect to it. An unfortunate accident at Lord Salisbury's estate was made use of as an object lesson to demonstrate the fearful consequences to the unhappy mortal who should be so venturesome as to have anything to do with electricity. Considering, however, the class of apparatus used in those days, the number of accidents that actually occurred was very small.[1]

So far, however, no serious encroachment on the preserves of the gas companies had been made, and they attempted to console themselves with the idea that the new light was quite unsuited to domestic requirements. For some time they boldly asserted this as a fact, and rejoiced in believing that the old order of things would be indefinitely prolonged; but the advent of the incandescent lamp soon caused them to alter their opinion and to redouble their opposition. Very soon the growing uneasiness developed into a panic, and gas shares fluctuated in

[1] Between 1880 and 1890 twenty-two lives were lost in New York by electrical accidents. The table in Appendix A gives an epitome of European fatalities for the same period, and for the last few years in England.

value in a most alarming manner. This was partly due, no doubt, to sensational eulogies of the new light indulged in by the Press, but chiefly to the fact that several applications were made to Parliament by companies seeking powers to enable them to supply electricity to different towns. About this time speculation of the wildest kind became rife, and company promotion became the order of the day.

Legislation affecting Electricity Supply.—In the year 1882, a Select Committee of the House of Commons having duly considered the question,[1] the first electric lighting Act was passed, which, however, produced universal dissatisfaction amongst those who were desirous of entering into the business of electrical supply. Section 27 of the Act was found to be far too onerous to enable a company to embark in electric lighting with much prospect of a satisfactory return upon the capital expended, and within twelve months such a serious depression took place that several of the companies then in existence went into liquidation. Of course restrictive legislation was blamed for this result, and there is not the slightest doubt that it was really largely responsible.[2] It must be borne in mind, however, that any modification in a dynamo or lamp, of no matter how trivial a character, and whether an improvement or not, was at once patented and seized upon by the company promoter for the purpose

[1] A Select Committee of the House of Commons in 1879 reported that the time had not then arrived for granting powers to supply electricity.

[2] On the other hand, Professor Fleming has stated that :—"There is no doubt that the Act of 1882, though much abused at the time, performed the important function of preventing the survival of the unfit" (*Electric Lamps and Electric Lighting*, p. 3).

of extracting money from a confiding public, and in spite of the brilliant prospect held out in the prospectuses of big dividends to those who would purchase shares in the various undertakings, the unfortunate shareholder was in the majority of cases doomed to disappointment, and dearly paid for his experience. The distrust in the public mind engendered by unfortunate speculation was without doubt partly the cause of the depression, and it was only to be expected that such wild enthusiasm and reckless speculation should result in a corresponding reaction.

Even some genuine companies were unable to obtain the necessary capital to carry on their business, while other companies came to grief through prematurely placing upon the market undeveloped and untried apparatus. At this time the number of central stations in existence supplying electricity to the public did not exceed half a dozen, and the majority, if not all, were without statutory powers. Some of these have survived, are in a flourishing condition, and are doing good work.

From 1883 to 1888 things were almost at a standstill, when the passing of the Electric Lighting Amendment Act and repeal of the objectionable section 27, forty-two years being substituted for twenty-one, and recurring periods of ten years thereafter, was the signal for the further promotion of companies and application to Parliament for the necessary powers. The large number of applications lodged for powers to supply metropolitan districts excited strong competition. With a view to ascertain the position and proposals of the applicants, Major Marindin held an official and public inquiry at the Westminster Town Hall in the spring of 1889. Witnesses were examined and objections lodged, each party being

given a fair hearing. As a general result[1] it may be said that uncontrolled rivalry was considered injudicious; that if more than one company were to be given powers in any one district, it was concluded that they should be working on different systems—say continuous for one and alternating for the other; and the metropolis was split up into areas, for which certain companies were duly granted the sought-for powers. A very large proportion of those who succeeded in obtaining provisional orders for districts scattered throughout the United Kingdom were unable, through want of capital, to carry on their undertakings, many of them being unable to proceed further than the engaging of the registered office and the appointment of the directors, the result being that the Board of Trade, after due inquiry, ultimately revoked their orders. The remainder who were successful in obtaining the necessary capital, including all the London companies, are still in existence, and most of them are doing a flourishing and rapidly growing business. Many of the large works now in existence owed their beginnings to private plants, which were at first put down to supply large residences or places of public resort.

Recent Progress.—In the year 1889, the number of electricity supply undertakings doing actual work was very small, and the enormous advance which has been made during the fifteen years ensuing is fully demonstrated by the fact that there are at the present time (1904) in Great Britain no less than 218 companies and local authorities engaged in the business, whose joint capital expenditure exceeds £36,000,000. Several of the most remunerative

[1] Parliamentary Return: *Report of Major Marindin to the Board of Trade, &c.*, May 9th, 1889: published June 17th, 1889.

districts in London are supplied by companies[1] who have been allowed to step in and undertake the supply of electricity, and to carry on a profitable business which might have been in the hands of the local authorities had they been foreseeing enough to have embarked in the enterprise. Many of the provincial corporations and local boards have made the same mistake, and, while it is still in the power of all local authorities to apply for concurrent orders, it is questionable whether the Board of Trade would consider it equitable to grant such powers in cases where the different districts are being properly and satisfactorily supplied by the companies in possession of the field.[2]

While electric lighting has been making rapid progress, the gas engineer has not been idle, and if "imitation is the sincerest form of flattery," he has done all in his power to flatter the electrical engineer by endeavouring to imitate the electric light as far as possible. Prior to the introduction of electricity for lighting purposes, the only form in which gaslight was known to the general public was the argand and batswing burners, chiefly the latter. Improvements were, however, soon introduced, and the Wenham sunlights, Bray, Sugg, and Siemens burners were soon in general use, while the boom in Welsbach incandescent burners has called attention to yet another

[1] The capital expenditure of the London companies exceeds £10,000,000.

[2] Manchester, which had a small two-wire station supplying a limited area, given up when Corporation works were started. Taunton, Bath, Southampton, Dover, Bray, Morecambe, Liverpool and Birmingham, and recently Marylebone and many others, have municipal supply, the undertakings having been purchased from companies who have found the transfer profitable. Stations were also started by companies in Colchester, Barnsley, and other places early in the eighties, but were afterwards abandoned.

attempt on the part of gas to oust its rival out of the field. That they are not very formidable rivals of the electric lamp is proved by the fact that they are frequently abandoned in favour of the latter. The colour of the light is considered most trying to the eyes, and the mantles are certainly exceedingly fragile, while they possess the disadvantage common to all forms of gas light, of consuming the life-supporting oxygen, and rendering the air unfit to breathe.

Electric lighting has not been without internal dissensions, and many questions have been left to his Majesty's judges to decide. Questions of patent law were largely the cause, the result being a transference of capital from the industry to the legal profession. Transformer distribution was prominently before the public in the actions Gaulard and Gibbs *v.* Ferranti, and Ferranti *v.* Gaulard and Gibbs. Compound winding and incandescent lamps attracted even more attention in the cases of King Brown & Co. *v.* The Brush Company, and the Edison-Swan Company *v.* Holland. In Hopkinson *v.* the St. James and Pall Mall Company the validity of the three-wire patent was contested and upheld. Many other but minor cases have appeared in the law courts, but, as master patents have lapsed and are diminishing in number, resort to litigation is becoming less frequent, and engineers are able to devote more attention to the legitimate development of the business.

The Position of the Industry.—The public are becoming educated to the advantages of electricity as compared with gas and every other agent used for lighting purposes, and the demand is increasing to such an extent that undertakers frequently find great difficulty in meeting it. The gas journals still continue to bring

forward the old worn-out platitudes and arguments against electricity—its danger, its prohibitive cost, &c., &c.; but in spite of all they or any one can say or do, it is evident that its future is assured, or it would have died a natural death long ago. Since its advent the standard of illumination has enormously increased, both for street lighting and domestic purposes; it is now universally recognized as the only light that conforms with the laws of hygiene, and, provided it is judiciously and properly used, it can usually compete with gas in price, without considering the fact that the cost of redecoration to rooms and damage to books and other valuable goods is saved, as well as many a serious doctor's bill.

It was a common practice when installing electric lamps and fittings to provide for far more light than was requisite, and certainly much in excess of that obtained previously with gas; due provision for proper economy by the use of sufficient switches was also frequently overlooked, and the natural result was a bill which was much in excess of what was anticipated, and the unfortunate undertakers had to bear the blame. Not unfrequently the new light was looked upon as a pretty toy, and kept alight at all hours and with an utter disregard to cost, in order to exhibit it to friends and neighbours. Probably all electric supply undertakers have found periodically a few—usually very few—consumers who complained of the exorbitant charge for electricity. This generally occurred at the end of the first quarter after they had commenced to use the light, and it was only necessary to point out that in such cases the first quarter's account was usually much heavier than any corresponding subsequent quarter, to show that the cause must be looked for in the lavish misuse of the light, and that the experience the consumers gained taught

them to turn off lamps when not wanted, and to reduce the amount of light within reasonable limits. In some cases, when this was pointed out by the undertakers as the previous experience of others, the consumers denied that in their particular cases they had either squandered or misused the light, and that the illumination was no greater than they previously obtained with gas. This statement, however, was invariably found to be somewhat doubtful if proper investigation were made.

Perhaps the greatest bane of both undertaker and consumer alike is the unscrupulous wiring contractor, and if an Act of Parliament could be passed for his total suppression the whole community would have cause to be devoutly thankful. It is a pity that the Board of Trade, when dealing with the new regulations, did not give the undertakers greater powers in this respect. At the present time clauses 41 and 42 are the only ones in the regulations dealing with the subject, and these only refer to the insulation from earth. It frequently happens that wiring is passed in consequence of the insulation being *at the time* fairly high, while the character of the work is as bad as it can well be, and very soon trouble arises. Unfortunately, by this time the contractor is elsewhere, his account has been settled, and he disclaims all responsibility. Inspection by the undertakers is frequently not possible, as the contractor who desires to hide bad work takes care that the consumer does not send in his application until the wiring is practically completed, and outwardly everything looks satisfactory. Should the insulation be sufficiently high, the undertakers have no alternative but to connect, and they are powerless to protect the consumer. If the Board of Trade would issue or approve a standard set of rules, with a penalty attached

for non-compliance on the wiring contractor's part, it would be a boon.

Expert Opinions.—"In a multitude of counsellors there is wisdom" is an ancient proverb, but those who embark in the electric lighting enterprise will, after an exhaustive inquiry into the merits and demerits of the various systems and appliances, come to the conclusion that in a multitude of counsellors there is nought but confusion and vexation of spirit, and, considering the wide divergence of opinion amongst experts on nearly all matters connected with electric lighting, it can scarcely be wondered at that some local authorities have declined to enter the business, but preferred to await the results of other people's experience.

That the electric lighting business has extended so rapidly is to be wondered at, in face of so many obstacles being placed in its way consequent upon the conflicting opinions of those whose greatest interest it is to forward the development of the industry. Although electrical engineers complained bitterly of the restrictive legislation which thèy said made electric lighting impossible, no sooner were the most onerous conditions in the first electric lighting Act removed by the amendment Act of 1888 than "The Battle of the Systems" commenced, and has been steadily maintained almost up to the present time. Although it doubtless originated with those who desired to advertise wares in the sale of which they were personally interested, it was evidently a short-sighted policy for contractors to confine their attentions to the manufacture of one type of apparatus, when it was to their best interest to cater to the public demands irrespective of the system; and it is a noteworthy sign of the times that some contractors who have for a long period manu-

factured apparatus suited to one system only, are now manufacturing and pushing the sale of machinery suited to the requirements of both systems. Of course we are particularly referring now to dynamos and electrical plant.

Some Technical Details.—After the unfortunate undertaker has decided upon the system to be adopted, and is congratulating himself that most of the difficulties are now over, he very soon finds that they have practically only just commenced; that he yet has to decide between the respective merits of high, medium, and low-speed machinery; horizontal, vertical, or rotary engines; Lancashire, tubular, and other boilers; storage and non-storage; solid mains and conduits; rubber, paper, jute, and other insulation; concentric, two or three core, and separate conductors; two, three, and five wires; 100 and 200 volt lamps; fixed and rotating armatures; and so on, and so on: and he is doubtless thankful to leave the decision of the whole matter to the discretion and experience of the professional expert, and so wisely relieve himself of the responsibility.

Even amongst the consulting profession, however, there is by no means a unanimity of opinion.

The Balance of Power.—In 1895 there were 62 undertakings, 31 of which were direct current and 31 alternating. In 1898 the number had increased to 99, of which 38 were direct and 54 alternating, while 7 adopted both systems. In 1900 there were 125, and of these 55 were direct and 52 alternating, the remaining 18 being a combination of both. At the present time (1904) there are 219 undertakings, of which 131 are direct, 55 alternating, and 33 combined.

The average capital cost per kilowatt of the 219 undertakings in Great Britain is for direct current stations £91, alternating £98, and combined £93.

That these figures are largely influenced by causes other than system is shown by the following table:—

	15 Metropolitan Companies.	44 Provincial Companies.	10 Metropolitan Local Authorities.	150 Provincial Local Authorities.
Total capital expended ...	£ 10,363,000	£ 3,405,000	£ 2,391,000	£ 19,886,000
Average cost per kw. ...	111	87	103	75
Average cost per kw. alternating ...	119	90	102	83
Average cost per kw. direct	92	100	104	68
Average cost per kw. combined... ...	122	71	—	75

The large increase in the number of direct current undertakings is probably due partially to the fact that the number of comparatively small provincial towns which have obtained provisional orders is increasing, and also that traction is being provided for.

Taking all the municipal undertakings in Great Britain, which number 160, it will be found that out of 95 who supply direct current, 45 show a profit and 50 a loss. Of those supplying alternating current, which number 44, there are 27 which have made a profit and 17 a loss; and where both systems are in use, numbering 21, a profit was shown in the case of 14 and a loss in the remaining 7. The following table may be useful for comparison:—

Total number of municipal undertakings = 160.

	Profit.	Loss.	Total.
Direct current undertakings	45	50	95
Alternating current undertakings ...	27	17	44
Combined direct and alternating current undertakings	1	7	21

In any event, there is no evidence whatever to show that either on the question of capital outlay, or working costs, either system can claim material advantage over the other, and either system, judiciously and properly worked, must ultimately result in equal profit to the undertakers; and thus there is absolutely no reason for hesitation on the part of local authorities or others who desire to embark in the business of the public supply of electricity.

The Commercial Aspect.—The inventive genius of the physicist and engineer has, during the past few years, done little towards cheapening the cost of production, and the reduction of the works costs must, therefore, of necessity now depend almost entirely upon the increase in the business; skilful management; upon the improvement of the load factor, and by holding out special advantages to those who take a supply of electricity during those periods when the machinery would otherwise be lying idle. That nothing succeeds like success is as true of electric lighting as of other things, and when success, in the form of a greater increase in the business, enables the undertaker to reduce the price of electricity to the consumer, there is not the slightest doubt that an improvement in the load factor will very soon be evident, thus bringing about a still further reduction in the cost of production, and therefore a further demand for electrical energy.

The further development and perfecting of the Nernst and mercury vapour lamps as well as the "flame" type of arc lamp is awaited with considerable interest, while the improvement in single-phase, alternating motors, and the extended use of polyphase currents and monocyclic systems will materially assist in the development and uccess of the business.

The dream of the electrical engineer of the ultimate

direct conversion of heat into electrical energy in such a manner that the loss in engine, boiler, and dynamo will be avoided, seems almost as far from realization as it ever was, and should it eventually be realized, it will probably prove the result of a slow process of development that will not materially affect the interests of existing undertakings.

There still exists the individual who persists in maintaining that electric lighting is still in its experimental stage, although he is ready to concede that it will probably be the light of the future. There are, however, few industries which have made such rapid advance in such a comparatively short space of time—and in spite of all the obstacles placed in its way by speculators, restrictive legislation, the widespread gas interest, and internal dissensions in the industry itself—than has electrical engineering; and that electric lighting is the light of the present, is quickly growing in popularity and has come to stay, does not require any proof beyond that which has been already demonstrated, while the use of electrical energy for cooking, heating, motive power, and other purposes, is steadily increasing, and will without doubt soon prove itself to be indispensable.

CHAPTER II

POWERS AND REGULATIONS

General Acts.—Although as early as the year 1879 the questions of electric lighting attracted the attention of Parliament, who referred the matter to a Select Committee for inquiry and report, it was not until 1882 that these inquiries resulted in the first electric lighting Act. It was entitled:—"An Act to facilitate and regulate the supply of Electricity for Lighting and other purposes in Great Britain and Ireland."

Unfortunately, instead of "facilitating the supply of electricity," it did a great deal towards stopping it altogether. This was chiefly due to the very onerous provisions which enabled the local authorities to purchase the undertaking of any company supplying electricity in their district under a provisional order, at the expiration of twenty-one years. The result was that few companies would risk their capital for such a comparatively short period, during which there would be very little prospect of a reasonable return. To fully appreciate the force of the objections held by business men to this section, it is necessary to bear in mind that any material reduction of price would have been impossible with so short a period by reason of the heavy annual provision which would have to be made for writing off by the end of the term

the capital of a company invested in plant and mains. Such a precarious tenure did not give sufficient inducement to lay down conduits and mains of such a character and capacity as to permanently provide for the supply of the district, and unless such provision was made the street works would only have been carried out from time to time as the demand arose, leading to periodical disturbance of the streets and footways and work entailing great expense, which would have rendered any material reduction in the price of electricity improbable.[1] So great was the dissatisfaction that in 1888 the Electric Lighting Amendment Act was passed, which extended the period of compulsory purchase to forty-two years.

It should be remembered that to the companies must be given the credit of pioneering the public supply of electricity, as at this time no local authority had considered it advisable to risk public money in the enterprise, and that therefore section 27, which would have been harmless in the case of local authorities—as it did not apply to them—was all the more onerous in the case of the companies, who were risking their capital in a new and undeveloped business, which could be taken from them as soon as it began to be profitable.

The general Acts contain provisions as to the issuing of powers authorizing the recipients to supply electricity, and state the manner in which application is to be made, the matters to be included therein, the general powers granted, and make it possible to recover charges for electrical energy used. Stealing electricity is classed as larceny, and made a punishable offence. Other sections give protection to canals, to mines, and to the telegraphic

[1] This was the argument used by a provincial company when urging the Corporation to consent to the granting of an order some years ago.

lines and works of the Postal Telegraph Department. Local authorities are given the power to borrow money for the purposes of electricity supply upon the security of their rates as defined by the Act. In return for these privileges, the undertakers have imposed upon them an obligation to supply electricity to every person who applies for the same in any part of an area where electricity is supplied "on the same terms on which any other company or person in such part of the area is entitled under similar circumstances to a corresponding supply.[1] The undertakers are not allowed to prescribe the use of any special lamp or burner, but the consumer must not use electricity in such a way as to unduly or improperly interfere with the supply of electricity to other consumers. The right of entry to a consumer's premises at all reasonable times is given to the officials of the undertakers for the purpose of reading meters and fixing or removing instruments or fittings.

Where the consent of the local authority to an application for powers by a company is required, the local authority, as guardians of the public interest, usually ask to be satisfied on the following points:—The stability of the company; that the area scheduled is a fair one, and that the cream of the district has not alone been selected, leaving out all the unremunerative portions, thus preventing the establishment of other undertakings; and that the system of supply is the most suitable, provision having been made to secure the benefits of any improvements which may from time to time be made in electric lighting or the supply of electrical energy. The electric lighting Acts provide three methods of acquiring powers for

[1] For discussion of the meaning of "undue preference," consult article in *Lightning*, vol. xi. p. 70, 1897.

the supply of electricity by companies, local authorities, and others, viz.:—(*a*) Special Acts of Parliament. (*b*) Licenses. (*c*) Provisional Orders.

Special Acts.—It would appear that the Board of Trade would probably oppose any application on the part of either companies or local authorities for special Acts,[1] and it is doubtless for this reason that very few, if any, special Acts have been either applied for or granted, except in the case of undertakings for bulk supply only.

In any case it is probable that such an application, which would inevitably meet with very strong opposition from various quarters, would be a very expensive matter, and would after all most likely result in failure. Even if a special Act were ultimately granted, it is questionable whether any material advantage would be gained over a provisional order, as it may be taken as certain that nothing in the form of a stipulated monopoly would be tolerated, and all the restrictions provided in the provisional order would be embodied in the Act before it was passed. These remarks apply only to undertakers who are also distributors, and not to undertakings for supply in bulk, of which more will be said later.

Licenses.—The granting of Licenses is now obsolete.

Provisional Orders.—The favourite method of obtaining powers under the Electric Lighting Act is by means of a provisional order, and nearly all companies and local authorities now supplying electricity are doing so under the powers conferred upon them in this manner. In the case of an application by a company for a provisional order, it does not appear under the Act of 1882 that the consent of a local authority was necessary. Section 1 of

[1] See *Law Relating to Electric Lighting*, p. 15 and following pages. (G. Spencer Bower and Walter Webb.)

the Electric Lighting Amendment Act of 1888, however, provides that the consent of the local authority shall be obtained before the Board of Trade will grant the order. It reserves power to the Board of Trade under certain conditions to dispense with such consent. The first step, therefore, on the part of a company desiring a provisional order is to obtain the consent of the local authority.

A provisional order enables a local authority, company, or person, known in the Act as the "undertaker,"—

1. To supply electricity under the Act for any public or private purpose within any area.
2. To break up the public streets, subject in the case of a company to the supervision of the local authority.
3. To acquire lands for the purposes of the order.
4. To construct works.
5. To acquire a license for the use of patents, inventions, machinery apparatus, &c.
6. To enter into contracts.
7. To generally do all acts and things as may be necessary and incidental to supplying electricity.

Works, however, can only be carried out by the undertakers subject to rules and regulations issued from time to time by the Board of Trade. These regulations are altered and amended periodically, and copies are issued by the Board of Trade. A Provisional Order under the Electric Lighting Act deals with the following points:—

1. *Area of Supply.*—The area of supply, which is always described in the first schedule to the order, has to be distinctly defined upon making application for a provisional order, and coloured red on the map to be deposited with the application, and represents the whole area within which (if the order be granted) the undertakers may legally supply electricity, and if they supply energy or lay down electric lines outside this area the Board of Trade may revoke the order.

2. *Security and Accounts.*—The undertakers have, within a period of six months after the commencement of the order, to show to the satis-

faction of the Board of Trade that they are in a position to carry out the work which they have undertaken. Separate accounts have to be kept in a form provided by the Board of Trade.

3. *Nature and Mode of Supply.*—Electrical energy can only be supplied by some "declared" system[1] which shall be approved by the Board of Trade and subject to their regulations. The mains can only be connected to earth with the consent of the Board of Trade and the Postmaster-General,[2] and the mains have to be laid in such a manner and the work generally carried out as to not injuriously affect, by induction or otherwise, other electric circuits, whether telegraphic, telephonic, signalling, or otherwise.

4. *Works.*—The undertakers are empowered to break up the streets, and construct distributing boxes for the purpose of leading off service lines and other distributing conductors, or for examining, testing, regulating, measuring, directing, or controlling the supply of energy, or for other similar purposes. Such boxes, however, must be for the exclusive use of the undertakers, and be under their sole control. Overhead wires are prohibited.[3] A month's notice with plan has to be served upon the Postmaster-General, the local authority, and (in London County) the County Council, of intention to break up the streets for the purpose of laying mains, and either of the three authorities may approve or disapprove of such works or plan. In the latter case they may require such alterations in the works or plan as they think fit. Where the streets do not belong to the local authority a similar notice and plan has to be submitted to the owner or owners of such streets. Notices have also to be sent to the owners of gas or water pipes near which electric mains have to be laid. Gas and water companies, in like manner, serve notices upon the undertakers.

5. *Compulsory Works.*—In the second schedule to the order, the streets in which it is proposed to lay down mains within a period of two years after the commencement of the order have to be clearly stated, and is known as the "compulsory area."

In addition to the mains specified in the second schedule, the undertakers must lay down distributing mains for the purpose of general supply throughout every street or part of street within the area of

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[1] For examples of "declared systems" see Appendix C.

[2] For conditions of consent see Appendix D.

[3] The common law right to erect overhead wires is in some towns controlled by by-laws framed under powers conferred by special sections of local improvement Acts.

supply, upon being required to do so in the manner specified by the order. If they fail to lay down such mains, they are subject to penalties, and run the risk of getting the order revoked. The requisition may be made by two or more owners or occupiers of premises situate in such street, and must be signed by the owners or occupiers making the requisition, and it must be served upon the undertakers, forms of requisition having to be kept by the latter for that purpose. The persons making the requisition, however, may be required to bind themselves to take a supply of electrical energy for three years, of such an amount in the aggregate as will, at the rate of charge for the time being charged for a supply of energy, produce annually at least 20 per cent. upon the cost of providing and laying down the required mains.

6. *Maps.*—The undertakers are required to keep a map of the area supplied, on a scale of at least one inch to eighty-eight feet, showing all the existing service lines and other underground works and distributing boxes, and copies of such map shall be served upon the Board of Trade, Postmaster-General, and (in London) on the County Council, and, in the case of companies, upon the local authorities.

7. *Testing.*—An electric inspector is appointed by the local authority (in the County of London by the County Council, and in the City by the Corporation of London) for the purpose of inspecting electric lines and works, and certifying meters under the order. The duties of such inspector consist of testing, from time to time, the insulation and conductivity of the mains belonging to the undertakers, as well as the service lines. These tests, however, must be carried out at such suitable hours as will least interfere with the supply of energy. He shall not, however, except under the provisions of a special order of the Board of Trade, be entitled to have access to the mains at any points other than those at which the undertakers have reserved to themselves access to the mains. After making a test, the inspector shall, within twenty-four hours, deliver a report of the results to the undertakers, and if the latter are dissatisfied with the report, they can appeal to the Board of Trade, who will thereupon inquire into and decide upon the matter, and their decision shall be final. The undertakers are required to establish testing stations at various parts of their districts, to contain suitable instruments of a pattern to be approved by the Board of Trade.

8. *Supply.*—The undertakers shall, upon being required to do so by the owner or occupier of any premises, situate within fifty yards from any distributing main in which they are required to maintain a supply of energy, give and continue to give a supply of energy to such premises

in accordance with the provisions of the order upon the following conditions :—The cost of so much of any electric line as may be laid upon the property of such owner or in his possession, and of so much of any such line as may be laid for a greater distance than sixty feet from the distributing main, shall be defrayed by the owner or occupier. The owner or occupier shall serve notice upon the undertakers specifying the premises in respect of which the supply is required, the maximum power required to be supplied, and also state when the supply is required to commence. A written contract must also be entered into, if required, to continue to receive and pay for a supply of energy for at least three years of such an amount that the rent payable for the same shall not be less than 20 per cent. per annum upon the outlay incurred in providing the necessary electric lines, and to give security for the payment of all monies which may become due. Should the occupier make use of the energy supplied for any purpose or deal with it in any manner so as to improperly interfere with the efficient supply of electricity to other persons, the undertakers may discontinue the supply, and they shall not be compelled to give a supply of energy to any premises unless reasonably satisfied that the electric lines and fittings are in good order and condition.

9. *Price.*—The undertakers may charge for energy supplied by them to any ordinary consumer (otherwise than by agreement) :—(*a*) By the actual quantity of energy so supplied, or (*b*) by the electrical quantity contained in such supply, or, unless the Board of Trade from time to time otherwise direct, (*c*) by the number of hours during which the supply of energy is actually used by such consumer, and the maximum power with which he is for the time being entitled to be supplied. Notice, however, in the case of a company must be given to the local authority, and, in the case of a local authority in London, to the County Council, before commencing the supply of energy through any distributing main, stating by what method they propose to charge for energy through such main, and they are not entitled to change such method of charging except after one month's notice to that effect has been given to the authorities in question. Where the undertakers have given notice to any consumer of intention to charge him by the number of hours and the maximum power as above described (*c*), such consumer, if he objects to that method of charge, may, by one month's notice in writing, require the undertakers to charge him by the actual quantity of energy supplied to him, and thereafter he shall not, except with his consent, be charged by any other method. The maximum price to be charged by the undertakers for energy supplied by them must be stated

in the fourth schedule to the order, and must not be exceeded. If after seven years from the commencement of the order, the County Council (in London), local authority, or the undertakers, make a representation to the Board of Trade that the prices or methods of charge stated in the schedule ought to be altered, the Board of Trade may, after such inquiry as they think fit, make an order varying the prices or methods of charge stated in the said schedule, or substitute other prices or methods of charge in lieu thereof, and they may be altered in like manner after the expiration of any or every period of seven years after they were last altered.[1]

10. *Meters and Apparatus.*[1]—The energy supplied to any ordinary consumer under the order must, unless otherwise agreed upon between such consumer and the undertakers, be ascertained by means of an appropriate meter duly certified under the provisions of the order. A meter is considered to be duly certified if it be certified by an electric inspector appointed under the order to be of some construction and pattern, and to have been fixed and connected to the service lines in some manner approved of by the Board of Trade, and to be a correct meter. If, however, the meter is altered or disconnected from the service lines it will require to be re-certified. The electric inspector is entitled to demand from the undertakers or consumer such fees as may from time to time be determined by the local authority, or (in London) by the County Council, with the approval of the Board of Trade, before certifying the meter. The undertakers must, when required by the consumer, supply him with an appropriate meter, fix the same upon his premises, and connect it to the service lines. They may, however, require the consumer to pay a reasonable sum in respect of the price of such meter or to give security for the same, or may require him to enter into an agreement for the hire of the meter and to pay the cost of fixing and connecting to the service lines and cost of certification. The consumer must not connect any meter with any electric line through which energy is supplied, or disconnect the meter from such line, unless he has given the undertakers not less than forty-eight hours' notice in writing of his intention so to do. The consumer is required to keep every meter which is his sole property in proper order for correctly registering the consumption of energy, failing which the undertakers may cease to supply energy through such meter, and they have the right to test and inspect any meter belonging to the consumer at their

[1] See "Electricity Supply Bill," p. 36, for amendments to these provisions.

own cost. Where the meter is the property of the undertakers, for which the consumer pays a rental, they must keep the same in repair. They may also let for hire any other apparatus or fittings upon such terms as may be agreed upon. Should any dispute arise respecting the correctness of the meter, such difference is determined, upon the application of either party, by an electric inspector.

11. *Notices, &c.*—All notices, orders, and other documents under the order may be in writing or in print, or partly in writing and partly in print, and may be served by being addressed to the body or person upon whom the notice is to be served, and left at or transmitted through the post. Where any notice is served by post, it shall be deemed to have been served at the time when the letter containing the notice would be delivered in the ordinary course of post, and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post. If not sent by post it may be delivered to some person on the premises, or if there is no person to whom the same can with reasonable diligence be delivered, by fixing the notice to some conspicuous part of the premises.

12. *Revocation of Order.*—The Board of Trade may revoke the order—(*a*) Either wholly or in part where the undertakers are insolvent and unable to fully and efficiently discharge the duties and obligations imposed upon them by the order. (*b*) Either wholly or in part where it is shown that the undertaking cannot be carried on with profit. (*c*) With the consent and concurrence of the undertakers and the local authority.

13. *General.*—Where any consumer is required to give security to the undertakers, and such security is given by the way of deposit, the undertakers shall pay interest at the rate of £4 per cent. per annum on every sum of 10*s*. so deposited for every six months during which the sum remains in their hands. Where the Board of Trade, upon the application of the undertakers, give any approval, or grant any extension of any time limit for the performance of any duties by the undertakers, due notice of such approval or such extension of time has to be given, and shall be published by public advertisement, once at least, in two successive weeks in some one and the same local newspaper by the body by whom such application was made. Where any application is made to the Board of Trade to extend any time limit for the performance of any duties, notice of such application shall be served on the local authority by the undertakers, and an opportunity shall be given to the local authority to make representations or objections with reference thereto. All penalties under the order the recovery of which

is not otherwise provided for, may be recovered in a summary manner before a court of summary jurisdiction. The undertakers are answerable for all accidents, damages, and injuries happening through the act or default of the undertakers, or of any person in their employment, in consequence of any of the authorized works, and shall save harmless all authorities, bodies, and persons by whom any street is repairable and all other authorities, companies, and bodies collectively and individually and their officers and servants from all damages and costs in respect of such accidents, damages and injuries. The usual saving clause for the Postmaster-General and (in London) for the Thames Conservators is included in an order. Nothing in an order exonerates the undertakers from any indictment, action, or other proceedings for nuisance being caused by them, or exempts them or their undertaking from the provisions of, or deprives them of the benefits of any general Act, relating to electricity, which may be passed in any future Session of Parliament. The schedules before referred to are as follows:—*First Schedule.*—Description of area of supply. *Second Schedule.*—List of streets and parts of streets throughout which the undertakers are to lay distributing mains within a period of two years after the commencement of the order. *Third Schedule.*—List of streets not repairable by the local authority, railways, and tramways which may be broken up by the undertakers in pursuance of the special powers granted by the order. *Fourth Schedule.*—The term "unit" as used in this schedule shall be deemed to mean the energy contained in a current of 1,000 ampères flowing under an electro motive force of one volt during one hour.

Section 1. Where the undertakers charge any consumer by the actual quantity of energy supplied to him, it is usually stated that they shall be entitled to charge him at the following rates per quarter:—For any quantity up to 20 units 13*s.* 4*d.*, and for each unit over 20 units 8*d.*

Section 2. Where the undertakers charge any consumer by the electrical quantity contained in the supply given to him, they are entitled to charge him according to the rate set forth in section 1 of this schedule, the quantity of energy supplied to him being taken to be the product of such electrical quantity and the standard pressure at the point of junction of the distributing mains and the service lines by which he is supplied; provided that where the undertakers' system involves a transformation of the energy supplied on the consumer's premises, the quantity of energy supplied to him may be taken to be the product of such electrical quantity and the standard pressure on the undertakers' mains divided by the number expressing the ratio of the transformation employed.

Section 3. Where the undertakers charge any consumer by the number of hours during which he actually uses his supply, they are entitled to charge him at the rates specified in section 2 of this schedule, the quantity of energy supplied to him being calculated on the supposition that the consumer uses the maximum power specified by him under the provisions of the order during all the hours that he has used the supply.

The Electric Lighting Clauses Act, 1899, has had the effect of considerably simplifying provisional orders as well as reducing the cost of obtaining them. This Act is described as "An Act for incorporating in one Act certain provisions usually contained in Provisional Orders made under the Acts relating to Electric Lighting," and includes all the provisions already dealt with under the head of "Provisional Orders" in the preceding pages. In addition to the foregoing there is also an Appendix which sets forth certain provisions of the Gas Works Clauses Act, 1847 and 1871, which are incorporated in the Act, and deal with the breaking up of the streets, laying pipes, waste or misuse of gas, injury to pipes, &c.

Loans and Capital.—In order to obtain the necessary funds to carry out the undertaking, a company is, of course, entirely dependent upon the sympathy and co-operation of the public. The usual prospectus is issued in which the promoters predict as favourably as possible the immediate and future prospects of the company they desire to float. Luckily for the public, the directors are now held responsible for any mis-statements that may be made in the prospectus, and probably unscrupulous promoters find much greater difficulty in floating bogus companies than formerly. Having issued shares and induced the public to subscribe the capital, the completion of the works is comparatively a simple matter. When however, further capital is required to extend the

business the trouble begins, and unless the directors have succeeded in paying a dividend in the meantime, the issue of preference shares or mortgage debentures becomes necessary, and the original ordinary shareholder's prospect of a dividend in the immediate future becomes very faint indeed.

In the case of a local authority, the necessary capital has to be borrowed, and consent to do so has first to be obtained from some other authority. With corporations this consent has to be applied for and obtained from the Local Government Board, while the London Borough Councils have to apply for and obtain the necessary consent from the London County Council, and in both cases certain conditions are laid down before the consent is given, the chief of which are as follows:—(*a*) The borrowing powers, which depend upon the rateable value of the borough, must not be exceeded. (*b*) The period within which the repayment of the loan with interest must be made is limited. (*c*) The manner in which the repayment of the loan is to be effected has to be approved.

In the case of provincial corporations, when application is made for permission to borrow, a date is fixed for a public inquiry, which is held by a representative of the Local Government Board. At this inquiry any person may make objection to the scheme. Should, however, no objections be raised, or should the Board consider them invalid or trivial, the necessary permission is given. The corporation is then at liberty to borrow the money on the security of the rates, the usual time allowed for repayment being twenty-five years. With the London Borough Councils no public inquiry is held by the County Council, but a statement is required of all the details of the under-

taking, and, if satisfactory, the Council themselves usually not only give their consent, but also lend the money.

It was at one time customary for the Council to give consent for borrowing the money for different periods, depending upon the purpose for which it was to be used: in the case of lands and buildings fifty years, in the case of machinery and plant twenty-five years, during which periods the whole sum borrowed, including interest, had to be repaid. Of late, however, a maximum period of forty-two years for the whole loan, including that for lands, buildings, plant and mains, has been adopted.

Local Authorities.—For the purposes of the electric lighting Acts it may generally be said that municipal corporations are the local authorities. They may enter upon electricity supply themselves, or if a company or companies are granted powers, then in them is vested the appointment of the electric inspector for the district of supply, and the enforcement of the testing and meter sections of the order. In the absence of a municipal authority, such as a city or town council, the urban or rural sanitary authority is held to be the local authority. In Scotland police commissioners would, in many instances, exercise such powers.

London occupies a curious position. For the City, the Corporation is now the local authority. Its predecessor, the Sewers Commission, allowed the supply to fall into the hands of a company, but to supervise the operations of this company it appointed an inspector. Outside the City, the County Council exercise some of the powers, and Borough Councils and district boards others of these. Thus the County Council appoint the electric inspector for the County of London, and would exercise the privi-

leges of undertakers over that part of the metropolis which they are authorized to light under the Public Health Act, 1875, section 161, and their special improvement Acts. The Borough Councils and district boards have, however, the control of the general lighting of their boroughs and districts, with the result that they may lay down works for the public and private supply of electricity under statutory powers, and many of them have done so.

Before the inquiry of 1889, the Commissioners of Sewers of the City of London were reluctant to permit any company to have a provisional order for the area within their control. The occupation of the subsoil by underground works in the City is exceptional, and the Commissioners desired that all powers for the disturbance of the surface should be conferred by themselves and not by statute. Owing to more than the ordinary rights of user of the soil of thoroughfares and streets being vested in the City Corporation, statutory powers were not necessary to enable them to grant way-leave. Major Marindin, however, reported against the claim of the City to be exempted from the operations of the electric lighting Acts, and, in face of opposition, recommended the approval by the Board of Trade of the applications for orders by two companies. These were afterwards merged into one.

Competing Companies.—Although statutory powers confer no monopoly upon those possessing them, there are certain well-defined principles by which competition is governed and a limit is placed against undue rivalry. Where a company is at work and doing its duty faithfully and well, supplying the needs of the public, there is a manifest disinclination to grant further powers for the same area, and any application is likely to be opposed by

the local authority and discouraged by the Board of Trade. Municipal authorities are given a preference in all cases where they apply before or at the same time as trading concerns, on the assumption that the power of purchase vested in them would probably have to be exercised sooner or later, and if a municipal supply be started within a reasonable time after the order is granted, the requirements of the districts should be satisfied, but if a supply be not entered upon, the order bids fair to be revoked or competitive concurrent powers granted. Where, however, one company is in possession of an area, it by no means follows that another company may not overcome any opposition to its application and eventually prove successful, provided always that the new-comer can show that it is offering facilities to the public that were not present before.[1]

Appointment of Officers.—When a company undertakes electricity supply it is, almost without exception, subject to the provisions of the various Companies Acts. In its memorandum and articles of association it enumerates the objects for which it is formed, and the means by which these are to be effected, such as purchase of land, erection of buildings, plant, &c., the appointment of officers and other matters of importance. To carry on its business it appoints a staff, the exact nature, number, and *personnel* being left to the discretion of the directors and managers.

A local authority in like manner has vested in it the

[1] In London as many as three different companies possess powers to supply electricity in the same district. With local authorities, however, the case is somewhat different, and as far as we are aware no order has been granted to a company in any district in which the local authorities possess the necessary powers and are carrying out work.

appointment of certain officers, for which purpose sections in the Towns Improvement Clauses Act, 1847, and the Public Health Acts, 1848—1875, give the requisite power in the case of medical officer of health, surveyor, inspector of nuisances, clerk, and treasurer. When an electricity supply scheme is adopted, other officers are required to manage the works and carry out the multifarious duties connected therewith. Although the appointment of such is not distinctly provided for, section 7 of the Electric Lighting Act, 1882, is sufficient to meet the case. This states that any expenses incurred by a local authority under this Act, and not specifically provided for, may be defrayed out of the local rate. Section 8 gives power to borrow money, and section 10 permits undertakers to acquire lands, construct works, enter into contracts, and "generally do all such acts and things as may be necessary and incidental to such supply" of electricity. The appointment and duties of that special official the "electric inspector" have already been referred to.

Board of Trade Regulations.—Briefly the regulations of the Board of Trade deal with the following points:—(*a*) Various definitions, including that of low, medium, high, and extra high pressure. (*b*) Regulations as to safety, including the pressure at which supply may be delivered at consumers' terminals; limitations as to high pressure and extra high pressure supply; maximum current in conductors; high and low pressure conductors laid in proximity; insulation of conductors; various regulations respecting conduits, converting stations, and consumer's premises; various regulations respecting aerial conductors. (*c*) Regulations as to supply, including notice of intention to supply through mains; the supply

to be always available; the maximum power supplied through any main; pressure on the mains; the fixing of standard pressure; declared pressure at the consumers' terminals; variation of pressure, &c. The regulations also state the maximum penalties for breach of the regulations.

The power to make and enforce regulations is given in the general Acts. By section 6 of the Electric Lighting Act, 1882, it is stated that undertakers may be subject to such regulations as may be inserted in any license, order, or special Act with regard to securing a regular and efficient supply of electricity, and for securing the safety of the public from personal injury, and from fire. It is also provided that the Board of Trade may make, amend, and repeal such regulations, while local authorities in whose districts supply is authorized may also make by-laws to further protect the interests of the public, but such local enactments shall be of no avail until approved by the Board of Trade. The last provision has not so far been taken much advantage of. The Electric Lighting Act, 1888, extended the scope of the Board of Trade regulations so as to include electric lines and works which are operated without statutory powers.

Provisional orders now state, under the heading "Nature and Mode of Supply," that energy shall be supplied subject to such regulations as the Board of Trade may impose.[1] The regulations are therefore issued separately, and do not form a part of, nor are they set forth in full in the orders, as was done with the early orders issued. A number of stringent and unnecessary restrictions upon technical points were contained in the

[1] Consult Summary of Requirements, Appendix E.

early orders, but these were replaced with advantage by a single clause in the Chelsea Order of 1886, which for the first time allowed more latitude, and gave a discretionary power to the Board of Trade. The Chelsea Order of 1886 was the model for those subsequently issued; an older one granted in 1883 to the Metropolitan Brush Company, Ltd., which lapsed within a year or two of its issue, followed the form of the earlier orders.

The technical provisions of the regulations are dealt with in the following pages under their respective heads. As central station supply is now established as a business under the statutory powers conferred by the principal Acts, the orders granted by the Board of Trade, and the regulations issued by the same department, engineers have to frequently refer to these documents. As a result there is a branch of electrical engineering which is only intelligently understood when it is studied in conjunction with its Parliamentary and legal literature. The purely technical aspect of electric lighting has already been exhaustively and ably treated by numerous writers, but to successfully supply electricity to the public calls for administrative ability on the part of those entrusted with the work which must rank equally with engineering knowledge and skill.

Accidents.—The Home Office and the Board of Trade must be notified in the event of any casualty taking place on the works or distribution system respectively. The Chief Inspector of Factories, representing the Home Office, was the official charged with the enforcement of the "very long, important, and complicated statute known as the Factory and Workshops Act, 1878," which consolidated and replaced about sixteen previous statutes.

The Factory Act gives the inspectors power to require

fencing to be erected round running machinery and "mill gearing," and impose certain restrictions on the employment of juvenile labour. If any accident occurs *inside* the works from mechanical causes alone, the Home Office must be informed; if the accident be solely or partly electrical, then the Board of Trade must be notified [1] as well as the Home Office. *Outside* the works the Board of Trade exercise jurisdiction, and where any serious casualty occurs from electrical effects an inquiry is held, and a report, frequently accompanied by recommendations, is afterwards issued.

The Home Office regard sub-stations as factories. A departmental committee of the Home Office appointed to inquire into dangerous trades, issued a report upon electrical generating works, which foreshadowed further regulations, as a number of recommendations were made affecting high-pressure generation.[2] Regulations have now been issued as to the construction of sub-stations, a summary of which will be found in an Appendix.

Amongst comparatively recent Acts which have been passed or Bills introduced which more or less affect the business of electricity supply, are the following:—

1. "The Factory and Workshops Consolidation Act," which, as its title implies, consolidates all the various Factory and Workshops Acts.

2. "The Factory and Workshops Amendment Act," which extends the power of the Home Office.

3. "The Workmen's Compensation Act," which places serious responsibilities upon undertakers in case of

[1] Second Interim Report, Dangerous Trades Committee, Home Office, 1897.

[2] A summary is given in Appendix F.

accident to employees. So onerous are its provisions that undertakers usually insure against accident under this Act as well as under the Employers' Liability Act and Common Law.

4. "The Electric Lighting (London) Act." The abolition of the London Vestries and the substitution of Borough Councils has necessitated the re-arrangement of the electric lighting boundaries in order to make them co-terminous with those of the various boroughs. For this purpose a Bill was promoted by the Board of Trade in 1901, but did not become law, and subsequent Bills have been presented each year. The last (1904) having been passed after considerable amendment of the original Bill of 1901. The title of this Act is "The Electric Lighting (London) Act."

5. "Supply of Electricity Bill (1905)." This Bill was promoted by the Board of Trade and presented by Lord Wolverton to the House of Lords. It contains several clauses of importance to undertakers, including clause 1, which provides for the compulsory purchase of land for generating stations—a clause badly wanted.

Clause 3, which allows of a supply in bulk by a provisional order.

Clause 4 gives the Board of Trade power to exclude the purchase clause (purchase by local authority) from the order in the case of bulk supply and under special conditions.

Clause 5 gives the Board of Trade, with the concurrence of the Local Government Board, power to enable two or more local authorities to combine for the supply of electricity.

Clause 6 in the original Bill repealed section 1 of the Electric Lighting Act, 1888, which virtually gave the local

authorities a monopoly in their boroughs, but this attempt to abolish their right of veto created such strong opposition in committee, that the clause was re-drafted in a much milder form, and at the same time applies only to those local authorities who are not actually supplying electricity.

Clause 7 deals with revision of the maximum price, and the period is fixed at five years instead of seven.

Clause 10 is a clause that has been badly wanted for a long time, viz. a "stand by" clause. Under the original Act any person within the statutory distance of the mains could require the undertakers to connect their premises and be ready to give supply whenever required, if only for a few minutes in a year, while they could run their own plant during the whole year and simply use undertakers' supply on emergency. The only recompense was a minimum charge of 11*s.* 8*d.* or 13*s.* 4*d.* per quarter, while it was quite possible and not uncommon that several hundreds of pounds capital would have to be spent by the undertakers. Such customers under clause 10 are now required to give a guarantee to pay an annual sum which will give a reasonable return upon the capital expended. The Bill as passed by the House of Lords Committee is a very different one to that first presented.

An attempt was made to get a clause inserted exempting undertakers from liability to action for nuisance, and, after several amendments, was ultimately adopted, but unfortunately the whole Bill failed to become law, and has been presented again in 1905.

The main object of the Electric Lighting Acts appears to have been to prevent large monopolies by supply companies by enabling local authorities whose areas were supplied by companies to purchase the undertaking after

forty-two years, it being evidently contemplated that the various generating stations and mains would be restricted to the limits of the respective borough boundaries.

Several companies have, however, been formed for the supply of electricity in bulk, and in these cases the generating stations are usually situated outside the area to be supplied, the trunk mains in some cases passing through several boroughs. It is obvious that such undertakings could not operate under the usual provisional order, and so special Acts have been obtained, and it has been pointed out that such undertakings render the purchase clause of the Acts inoperative. Legislation has been sought in order to enable local authorities to combine amongst themselves, or in conjunction with the London County Council, to purchase such undertakings.

There is at present apparently no definite interpretation of the word "Bulk," and this has led to a great deal of confusion.

The London County Council have endeavoured to obtain powers to lend money to the London undertakers for free, wiring purposes, and hire or hire-purchase of motors and other matters, but as yet without success. A Clause to this effect appears in the London County Council General Powers Bill, 1905.

CHAPTER III

ELECTRICITY SUPPLY AND ELECTRICITY WORKS

THE generation and distribution of electrical energy is in many respects similar to the production and distribution of gas, as each requires:

(a) Generating plant } Under the control of the supplier.
(b) Distributing plant }
(c) Consuming devices—Under the control of the consumer.

These consist of the following appliances:—

Electricity.	*Gas.*
(a) Boilers, engines, dynamos, batteries.	Retorts, purifiers, gas-holders.
(b) Mains and services, transformers, switches and regulators, meters.	Mains and services, valves and regulators, meters.
(c) Various forms of burners (and motors).	Various forms of burners (and motors).

In each case, of course, the generating plant (a) requires appropriate buildings for its accommodation. As, however, the storage of electrical energy so called is really only the transformation of electrical into chemical energy, there is nothing in an electricity works analogous to the gasholders in a gas works, and even where storage batteries are adopted their use is generally confined to the regulation of pressure, to meet the extra demand

during the peak of the load (which only continues for a short time), or to take the reduced load during the small hours of the morning or during the daytime in stations with a small day demand.

Expert Advice.—Before commencing work it is usual to appoint a consulting engineer to report upon the system to be adopted, the best position for the site, to draw up plans and specifications of the plant and works, to issue advertisements for tenders, to report upon and advise as to the various tenders received, and to superintend the erection of the works, putting down of the plant and laying of the mains, and also generally to advise on all matters connected with the undertaking. In other cases, however, an electrical engineer has been appointed in place of a consulting engineer, to undertake the duties of the latter, and to have charge of and manage the works when completed. It goes without saying that a consulting engineer should not be connected either directly or indirectly with any firm of contractors, nor should he be interested in the manufacture or sale of electrical apparatus or machinery or plant.

Large undertakings require as resident or managing engineer one who should be competent to carry out the preparation of a scheme, whereas in smaller works this is not so essential, the resident engineer only being required to run the station. The reason in the former case is that it is now customary to entrust the designing of detail extensions to the resident engineer, and even if he is not actually entrusted with the initiation of plans, &c., he should be able to supervise thoroughly the work for which he will be responsible afterwards; on large stations the distribution, buildings, and staff will be on a more liberal scale than in restricted districts, and greater

responsibility is entailed in the management of matters appertaining to them.

The Choice of a System.—The points to be considered when the system to be adopted comes up for settlement are:—

1. First cost.
2. Economy in supply.
3. Reliability.
4. Varied sources of revenue.
5. Safety to life and from fire.
6. Disturbance of telephonic and telegraphic communication.
7. Ease of regulation and measurement.
8. Flexibility.

Electricity supply undertakings now in existence in this country employ one of three systems, namely:—

(a) Low-pressure continuous current. (Direct supply.)
(b) High-pressure continuous current } Converted supply.
(c) High-pressure alternating current } Converted supply.

From the published accounts of the various undertakings it appears that very little can be claimed by any one system over the others[1]—1. On the question of capital outlay; 2. On the question of working costs; although it is quite impossible, unless the local conditions governing each particular case are known, to draw anything like a fair comparison between the different undertakings. 3. With respect to reliability no one system can claim any material advantage over the others. Continuity of supply depends more upon careful selection of plant and skilled supervision during erection and when at work than upon the pressure at which the system is operated. Satisfactory insulation can be assured up to the limit of high pressure, while generators and converters are built with which no trouble need be anticipated, pro-

[1] See an article by one of the writers, *Elect. Review*, vol. xxxviii. p. 33.

vided the best of the respective classes are procured. Any advantage which direct low-pressure supply may have possessed in years gone by has now been reduced to a vanishing quantity, so far as security from interruption goes, as breakdowns need not embarrass the engineer who has adopted high pressure, provided that all parts of the system have been selected with due regard to the stresses —mechanical and electrical—to which they are likely to be subjected when in action.

It has already been pointed out that secondary batteries do not materially increase the security of a system, inasmuch as the capacity provided is seldom sufficient to take the load for any length of time worth considering from this point of view.

4. In industrial districts there is a rapidly growing demand for electricity for motive power, and as motors are generally in use more or less all day long, the ambition of the central station engineer for a high load factor bids fair to be realized, and the improvement in single-phase alternating motors has enabled supply undertakings on that system to satisfactorily meet the demands of consumers. Numbers of motors of this class are now in use up to 100 h.-p., or more.

In districts where motive power forms the greater part of the business the direct current has some advantages, but in a mixed lighting and power business it is not so important, and in the case of large power schemes polyphase alternating systems are now usually adopted.

For purposes of cooking and heating both systems are equally suitable, while for electric welding[1] (a growing

[1] The nature of the load due to electric welding is not, however, such as renders this class of business a very desirable one on mains where lighting is the predominant factor.

industry with probably a great future) the alternating current possesses certain advantages.

5. As high-pressure systems distribute at low pressure there is little difference in the relative security accorded to the public. The danger to life is confined to the high-pressure system, access to which is reserved to the staff of the undertakers, who are, or ought to be, skilled men, and fully alive to the risks run, and how personal safety can be secured. The consumer only knows:

In the case of continuous current,	In the case of alternating current,
1. Declared pressure.[1]	1. Declared pressure.[1]
	2. Frequency.

The Board of Trade regulations provide for the personal safety of the public and of consumers, and to some extent protect the consumer's premises against risk of fire; the fire offices, whose business is the repayment of losses, strive to minimize the risk by requiring wiring to be done in such a way that, if their rules are complied with, good and reliable work is insured. A 500-volt continuous current shock is decidedly unpleasant, and might under certain circumstances prove fatal, but up to 250 volts the danger to life is very remote indeed.

6. The burden of avoiding disturbance to telegraphic communication is placed by law on the undertakers. It may be said that whatever will affect the telegraphic system will interfere with the telephone business, and any cure for one will meet the case with the other. No fear need arise, however, with regard to any system complying

[1] From a customary minimum of 100 volts to a legal maximum of 250 volts.

with the Board of Trade regulations. Concentric cables solve the difficulty in nearly all cases, and good insulation goes a very long way.

7. It would be difficult to prove that in the present day there is any real complexity in the regulation or measurement of alternating pressures or currents. Instruments have been so carefully designed, their action and behaviour have been so thoroughly investigated, and the modes of using them developed, that measurements can now be made in every-day work as accurately as there is any need for. Of late years trained observers—the product of the many excellent training colleges—have been turned out in even greater numbers than is warranted by the demand, and in their hands the tests forming part of station routine are all that could be desired. Thus the argument which had weight in times past has lost its force.

There is little to choose between supply meters intended for continuous, and those for alternating supply. At any rate, the difference is not sufficient to turn the balance one way or the other. Regulation on the alternating system is simplified by the use of boosters and other apparatus molecular in action. The ease with which the pressure-current ratios is changed may at times prove an advantage. Regulation with continuous current has to be attained by a less direct method, but these considerations affect the design of a station equipment rather than the choice of system, which is determined by more important matters.

8. Only a few years ago the suitability of the system depended very largely upon the size and nature of the area to be supplied. The then low-pressure system meant a supply at or about 100 volts, and it was prac-

tically impossible to supply a large area [1] at such a low pressure without a prohibitive expenditure for the mains or by erecting a number of stations in various parts of the area, and so dividing it up into comparatively small districts. When the area was a straggling or scattered one it was therefore almost invariably the rule to adopt the alternating system, which required only one central station, and enabled overhead wires to be used and outlying districts to be supplied with small mains without any serious drop in pressure.[2] Since the adoption of the three- and five-wire systems, however, and the legalized increase in pressure at the consumers' terminals, distribution over comparatively large areas has become possible with the low-tension system, without unduly subdividing the centres of generation. Where the area is small or compact the high pressure is altogether unnecessary, and in many ways low pressure would be more suitable; but it is probable that the alternating system is still preferable in large or scattered areas where it is considered desirable to work from a single centre.

The Site.—The selection of a site for a central station is a matter of considerable importance, and requires very careful consideration.

It may be advisable to decide upon the system of supply and the type of plant to be used before the question of site is considered. In some cases, however, the site may determine both the system and class of plant. As a case in point, suppose a piece of land is available on

[1] Although the best portions of a large area might—and have been—so dealt with.

[2] E.g. London (Grosvenor Gallery), Brighton (Co.), Glasgow (Co.), Cathcart.

the banks of or near to a river which has a fairly constant flow and a good head of water, but which is situated at some considerable distance from the district to be supplied. Obviously, the system selected should be a high-tension one (whether continuous or alternating), and the motive power should be water through the medium of turbines, provided that the cost of the land is not prohibitive, and that the water is available for the purpose described.[1] The cost of production would thus be materially reduced, the most expensive item—viz. the coal bill—being avoided.

Where no such favourable conditions exist, the system may largely determine the location of the site. Where other considerations are not paramount, it is always advantageous, no matter what system is adopted, for the site to be located as nearly as possible in the centre of the district to be supplied, as distribution becomes much simpler and the loss is reduced. The proximity of the works to a line of railway from which a private siding may be laid down is also a desideratum, so that the delivery charges for the coal may be saved. If a site can be selected near a canal or other available water, condensing engines can be used, and a considerable reduction of the coal bill will result, provided no serious restrictions to the free use of the water exist, or if it may be used for a nominal charge. The means of obtaining free or cheap feed-water for the boilers is a matter of importance, as the cost of water when obtained from a company's service is a serious addition to the cost of production, and may be

[1] Unless great care be taken in assessing the value and constancy of water power, one is liable to overrate the prospective advantages to be derived from its use.

saved if canal or other available and suitable water is near at hand.

In order to avoid legal troubles the works should be isolated and situated as far as possible from any property the owners of which might object to vibration or noise, as even in the most carefully designed works it is very difficult, if not impossible, to prevent one or the other, and many companies have been badly hampered by continued litigation in consequence. The suitability of the ground for foundations of buildings and machinery must be considered, and a virgin subsoil of hard clay or gravel is probably most suitable, care being taken to divert all springs or water-courses, and to thoroughly drain the land so as to get rid of surface water. The selection of an otherwise suitable site may entail a large expenditure in piling if the ground is at all boggy or unstable in character. The sinking of trial holes may save considerable expense by proving the unsuitability of the ground before instead of after purchase.

The question of approach, although not always considered, is important, and if there is the means of access to the works from more than one direction it will be found to be very convenient for distribution as well as for the delivery of goods and machinery. The property should, of course, be purchased outright if it is possible to do so and without serious restrictions. A central station erected on leasehold property must of necessity mean the placing of a serious burden of difficulty upon a future generation, and the more successful the business, and the larger the district supplied, the greater is the power placed in the hands of the freeholders.

The site should be sufficiently extensive to allow of all probable extension required for many years, unless

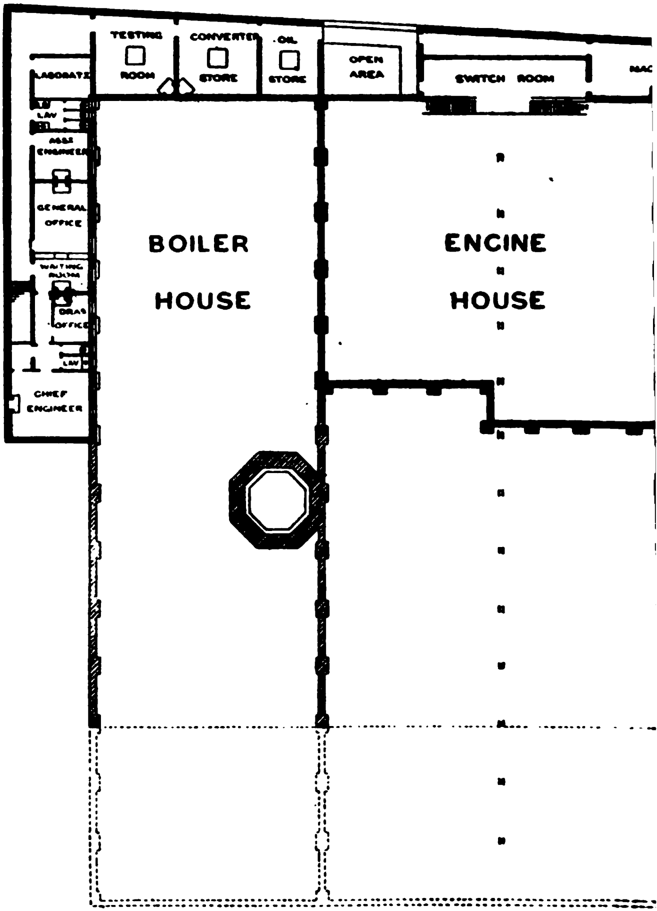
the surrounding property be of such a class that it may be readily purchased when wanted. Sometimes it is found that the interests in property required for extension are divided up, and are very much involved, while its value to the owners suddenly increases to an alarming extent when they find it is in demand by a local authority or company, who are usually considered fair prey by unscrupulous landowners.[1]

Buildings.—Briefly, the buildings for an electric lighting station consist of a boiler house, coal store, and chimney stack, an engine and dynamo house, switch-rooms, offices and stores, workshops, and a separate accumulator-room, if accumulators are used.[2]

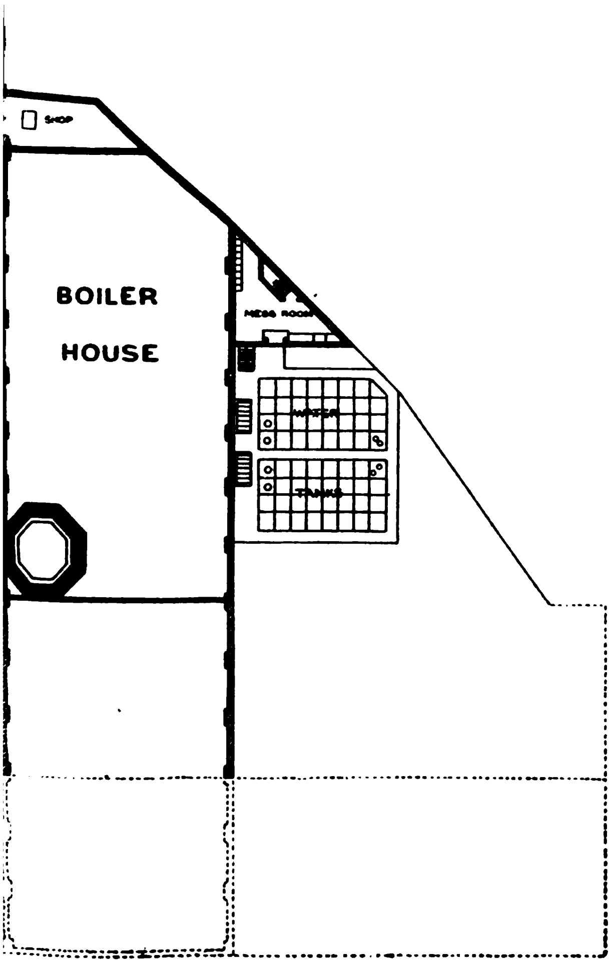
The dimensions will depend upon the type of plant adopted, the extent and character of the district to be supplied, and the probable immediate demand. When it is obvious that the demand must be small for some considerable time, and that the growth of the business will be slow, large and expensive buildings are, of course, out of the question, and it would be most unwise to incur any great outlay upon that portion of the works which must of necessity be unremunerative. In such a case it is usual to erect only a boiler house, coal store, and chimney stack, engine house, and, where required, an accumulator-room—temporary provision being made for general stores, workshops, and offices, until such time as the increase in business justifies additional outlay. The switch-

[1] Lord Wolverton's "Supply of Electricity Bill" (1905) contains a compulsory purchase clause.

[2] See a paper by Mr. C. Stanley Peach, F.R.I.B.A., read before the Royal Institute of British Architects on March 28th, 1904, entitled, "Notes on the Design and Construction of Buildings connected with the Generation and Supply of Electricity known as Central Stations."


TESTING ROOM
CONVERTER STORE
OIL STORE
OPEN AREA
SWITCH ROOM
LAV
GENERAL OFFICE
CHIEF ENGINEER
BOILER HOUSE
ENGINE HOUSE

Fig



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board is erected in the engine-room, and what clerical work is required to be conducted can be carried on in a small room partitioned off from the engine-room, or, in case a special office is considered necessary or requisite, it need only be of the simplest possible character. When a large immediate demand is anticipated, it is probably wiser to erect at once a full complement of offices and stores for all probable future requirements, and the only extensions then necessary will be in the direction of the engine and boiler houses, and possibly the accumulator-room, and if this is properly arranged, little or no interference with the running machinery need occur. An example of one arrangement is given in fig. 1. The corresponding ground plan will be found in fig. 2.

An architect should be engaged to draw up the specification for the buildings, to superintend their erection, and to be generally responsible; but the laying out should undoubtedly be done by an electrical engineer, either alone or in conjunction with the architect. A good arrangement is for the engineer to draw up his own plans, and for the architect's plans to be kept as nearly as possible to them.

Durability.—When it is remembered that an electric-lighting business is a progressive one, that its growth will probably continue for an indefinite period, and that every year it will become more difficult to make structural alterations to or to reconstruct the buildings, on account of interference and risk to the running machinery, it is obvious that the buildings should be constructed only of the very best material and in the most substantial and durable manner. Where the prospects of the undertaking justify the outlay, the buildings should always be constructed of high-class brickwork, stone, or similar durable

material, with steel and Portland cement, instead of wood joists and floors. Indeed, there should be as little woodwork or other perishable material as possible. In the case of a company it is, of course, absolutely essential to the success of the business that the capital expenditure, particularly upon unremunerative work, should be kept as low as possible, as until the dividend-paying stage is arrived at, the prospect of obtaining further capital for development will probably be very poor. With a local authority the case is very different, and any attempt to keep down the capital cost at the expense of durability in order to show a net profit during the first year or two is a very questionable policy.

All provisional orders provide that the electricity supply, when once commenced, must be maintained without interruption, and therefore any extensive repairs to or reconstruction of the building becomes a very serious and costly matter, to say nothing of the risk of disablement of the plant due to hot bearings, &c., consequent upon gritty matter flying about, and which it is impossible to entirely prevent. Again, it is always inadvisable, if not dangerous, to allow workmen, other than the departmental staff, in any part of the works where there is running machinery.

Protection against Fire.—It goes without saying that all electricity works should be practically fireproof, as a serious outbreak of fire would mean the disorganization of the whole lighting system and the stoppage of the supply for possibly a considerable period. The greatest risk from fire naturally exists at the switchboard, more particularly in a high-pressure station, and although some engineers do not deem it advisable, for many reasons, that the framework supporting the switchboard should be of metal, yet the switches themselves should be mounted on

non-hygroscopic, non-combustible material of solid construction, and the framework, if of wood, should be steeped in some fireproof compound and painted with asbestos paint, or covered with asbestos sheeting. In the case of a single pole switchboard it is now the general practice to build the switches and gear into a brick wall the panels being isolated by means of heavy slate or other non-combustible material.

In large high-pressure works it is always advisable for the switchboard to be erected in a special room, either partially or entirely separated from the engine-room, but at the same time overlooking it, and to be so constructed that should an outbreak of fire occur either in front or behind the board, it could be readily reached and extinguished. The works should be divided up and each section separated from its neighbour by means of well-constructed iron doors, so as to isolate and so check the spread of any fire that may occur. Plank floors and wooden partitions should be avoided, as well as all flimsy lath-and-plaster erections or facings to the walls.

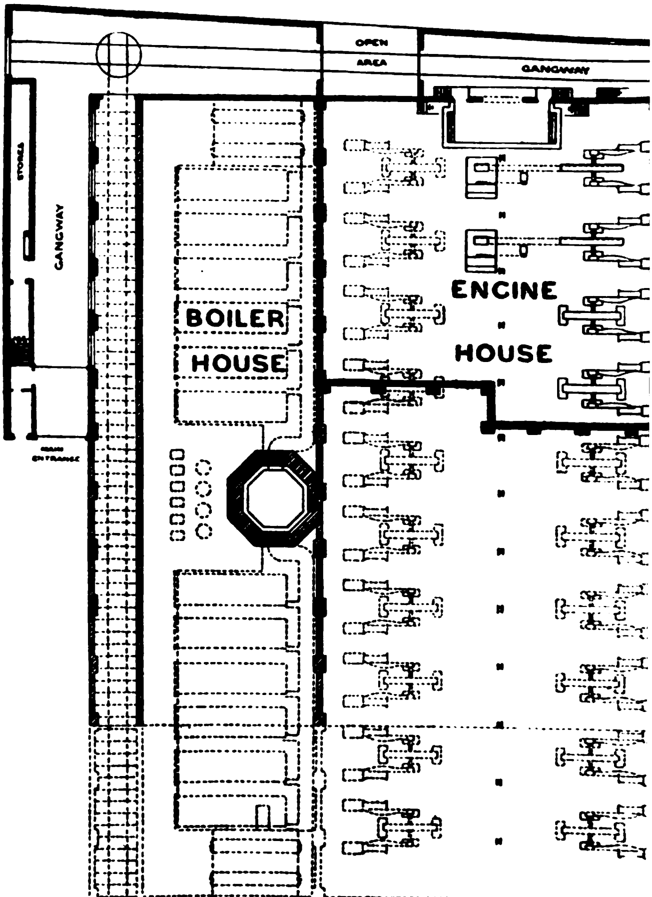
A full complement of fire-extinguishing apparatus, including hand grenades, fire buckets (which should always be kept full), and hydrants or pumps, should be provided, all of which should be used judiciously in case of fire, or the intended remedy may only increase the trouble. Automatic sprinkling appliances should be avoided. It is scarcely necessary to remark that protection against lightning is equally necessary, and not only should the stack be efficiently protected, but the buildings also, while all large masses of metal should be properly earthed.

Cleanliness and Ventilation.—Cleanliness should be considered a necessity in every well-conducted electricity works, and the day has long since gone by when it was

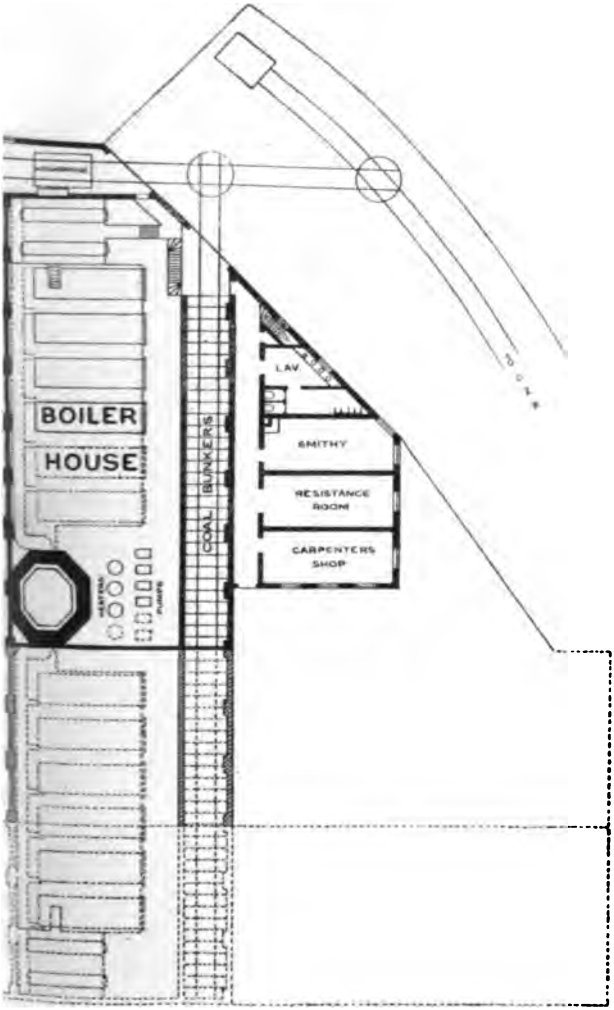
considered business-like for an engine-room to be reeking with oil and dirt. The adoption of white glazed bricks as a facing to the walls, although a somewhat expensive item, enables the accumulation of dust and dirt to be prevented, and, provided there is a reasonable amount of top light, the walls act as reflectors and cause a general diffusion of light, which frequently obviates the necessity of artificially lighting the place at times when it might otherwise be necessary. A well-ventilated engine and boiler house should be deemed a necessity, as it is little short of cruelty to expect men to work in a temperature of perhaps 115° F. or 150° F. for eight hours at a stretch. At the same time, proper ventilation frequently prevents illness and consequent disorganization of the staff. Again, the temperature of any room in which machinery is running should always be kept within reasonable limits if hot bearings as well as over-heating of the coils of the armatures and magnets of the dynamos is to be prevented.

Accommodation of Staff.—This is a point frequently overlooked, but most modern stations now include changing-rooms, mess-rooms, and lavatories for the workmen, and although it may not be always appreciated as much as it should be, there is little doubt that the men will do their work more willingly and in better spirit than when their interests are not considered.

Provision for future Extension.—In designing the buildings, the question of future extension should always be borne in mind. There sometimes appears to be an inclination to look after the present, and to let the future take care of itself. It is a very simple matter to design a building of four walls, roof and floor, to contain the two or three dynamos, engines, and boilers with which an


OPEN
AREA
GANGWAY
STORES
GANGWAY
BOILER
HOUSE
ENGINE
HOUSE

Fi


BOILER
HOUSE
COAL BUNKERS
LAV.
SMITHY
RESISTANCE
ROOM
CARPENTERS
SHOP

2.

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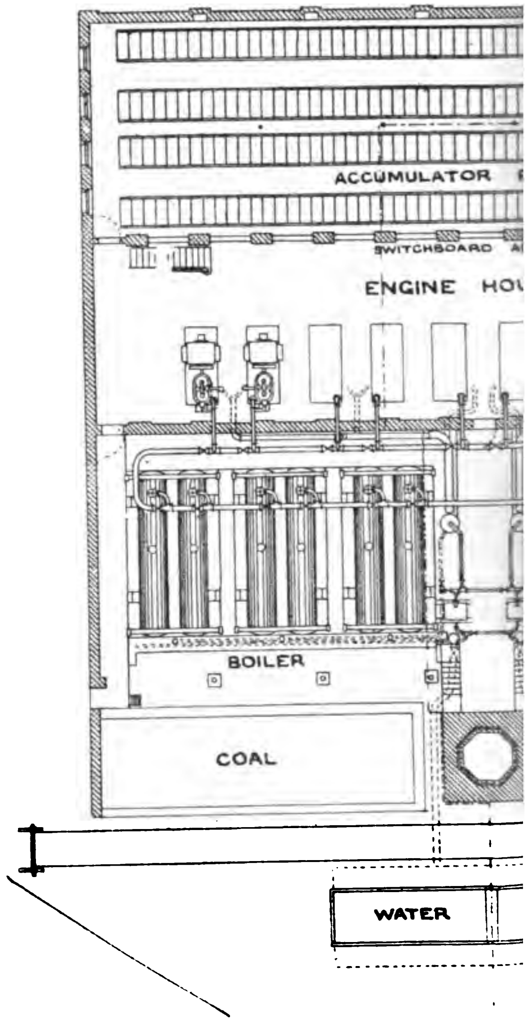
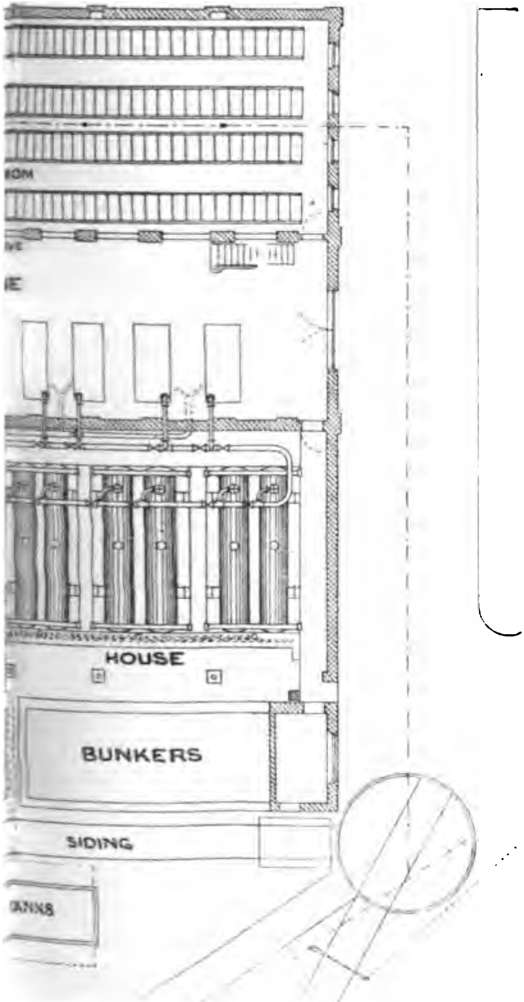


Fig



4.

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undertaking frequently starts; but to provide for years to come in such a way that the extensions can be carried out in a systematic manner and with regard to the best arrangement for efficiency and economy, and with the least interference with the existing plant, is a very different matter, and requires very careful consideration, or it may be found that when extensions become necessary the original plan cannot be followed, with the result that structural alterations are necessary, or the plant has to be divided up in a way that renders proper supervision difficult.

Facilities for the Delivery of Stores and Coal.—The advantages to be derived from the close proximity of the works to a line of railway or canal cannot very well be over-estimated. In London the cartage of coal varies from 2*s.* to 3*s.* per ton, the whole of which may be saved by having the coal delivered in trucks direct into the works and as the consumption of coal frequently amounts to many thousands of tons per annum, and of course increases with the growth of the station, it will be seen that considerable economy will be the result. In cases where a line of railway adjoins the works the boiler house can be excavated some ten or twelve feet below the railway level and coal bunkers erected facing the boilers (compare figs. 2 and 4). A railway line can then be laid directly over the top of the coal bunkers, and the coal delivered in end-tip or bottom-trap trucks, when in either case it can be shot out directly into the coal bunkers, and the cost of unloading very much reduced. The juxtaposition of the railway also enables the machinery and stores to be delivered direct on to the premises, thereby facilitating delivery and considerably reducing the cost.

Foundations.—All the foundations of both the buildings

and machinery must be of the most substantial and durable kind, so that the risk of settlement is reduced to a minimum. Slight settlement is unavoidable, but should it occur to any appreciable extent, the result may be most serious, as the machinery may be thrown out of line, the bedplates cracked, steam pipes ruptured, and in bad cases even the boilers jeopardized, to say nothing of the risk to the building itself.

Special precautions are necessary where the boilers are set on a clay soil, as serious settlement is liable to occur due to the heat from the furnaces and flues drying out the moisture in the clay and causing it to contract. Unequal settlement then takes place, resulting in dangerous stress not only in the boilers but also in the flanges and steam connections. Cracks are also produced in the walls and flues which admit cold air and considerably increase the coal bill. A steel framework or a heavy bed of concrete or a combination of both should extend along the whole length of a battery of boilers.

The footings of the walls should be ample, and where the ground is at all unstable they should be laid on concrete, after the ground has been made as firm as possible with broken stone or brick. Solid brickwork or stone laid in cement probably makes the best foundation for machinery, as concrete is liable to be affected injuriously by oil or grease and to crumble away, besides which it is more liable to throw off gritty particles than brick or stone, and is less easily repaired than the latter.

The foundation of the stack requires special attention, and the ground should be excavated with a view of obtaining as solid a bottom as possible. A solid, homogeneous bed of Portland cement concrete should then be laid, the work upon which should continue uninterruptedly. This

bed should extend some feet beyond the footings, the number of courses in the latter, as well as the thickness of the concrete, depending, of course, upon the dimensions of the stack. The concrete should be allowed to thoroughly set before building is commenced. Sometimes a composite 'raft' of steel joints has to be constructed, as concrete alone would be unreliable. In very soft or unstable ground special precautions are necessary, and it may necessitate extensive excavation, ballasting, &c., or special foundations made up of piles, driven down, and a framework of balks or steel girders laid on the top, upon which the buildings are erected.

Boiler House.—The boiler house should be several feet below the ground level, provided that the depth of the sewers in the district is such as to allow of proper drainage, and that there is no risk of serious flooding during stormy weather, for, although the excavation will be somewhat costly, it will very soon pay for itself by the saving in handling and delivery of coal, more particularly if the building adjoins a line of railway, and a siding is arranged above the coal store. Where possible, the coal bunkers (which should be close to and facing the boilers) should have sufficient capacity to permit of storing three or four weeks' supply, as by this means the second handling of the coal, and therefore extra labour (which would be necessary if a separate coal store were used), is avoided.

When the boiler house is below the ground level all the steam pipes rise direct from the boilers to the engines, and therefore there is less chance of water being carried over to the cylinders, while the supply pipes to the engines can be placed below the engine-room floor level in a position most suitable for frequent inspection and for

effecting repairs when required. Not only should the boiler house immediately adjoin the engine house, but it should also run parallel with the latter, especially if the site permits of extension in the same direction, so that the steam pipes can be kept as short as possible. It will be at once seen that a boiler house at right angles to the engine house means that every extension necessitates the new boilers being fixed at a greater distance from the engine, and the steam pipes and connectors become disproportionately long, and increased risk and radiation must necessarily follow.

Provision must be made for the pumps and heaters as well as for the economizers, if they are to be used. When the stack is erected in the boiler house, and particularly if it is central, a favourite and suitable place for the heaters and feed pumps is directly facing the stack, as by this arrangement the distance that the feed water has to be carried is minimized. If the stack is at some distance from the engines, the position mentioned would be unsuitable for the heaters, as they should be as near the engines as possible, in order that the temperature of the exhaust steam should not be too low.

As the economizers require considerable floor space, their exact position will depend somewhat upon the general design of the works. They must, however, be fixed in a bye-pass to the main flue and consequently near the stack.

The floor of the boiler house may be of concrete, York stone, or other suitable non-combustible material, all woodwork being avoided. Concrete or blue brick forms a good paving for the coal bunkers. A trench must be left in front of the boilers for the blow-off pipes,

feed pipes, &c., and this is usually covered with removable chequer plates of iron laid on iron joists.

Chimney Stack.—The chimney stack is perhaps the most important part of the whole building, and too much attention cannot be paid to its construction. A thoroughly solid foundation is absolutely essential, and the building should proceed very slowly indeed, or unequal settlement may occur, probably resulting in the cracking of the stack. The interior must be lined with firebrick built in fireclay and separated from the stack by an air space of three or four inches. This firebrick lining, if not continued to the top, should certainly be carried to a height of at least forty or fifty feet above the firing level. The air space should be covered at the top to prevent cinders accumulating within, or they may take fire and cause considerable local heating and possibly cracking of the brickwork. Ventilation of the air space is also necessary, and this may be done by means of holes carried through the lining into the stack in such a manner that cinders cannot pass, or by taking the ventilators through the stack into the open air. The brickwork of the stack should be thoroughly bonded together, although not unfrequently stacks are constructed by unscrupulous contractors which are simply an outer and inner shell filled in anyhow, and trouble inevitably ensues sooner or later. At the base there should be a well or pit two or three feet below the level of the flue floor to catch the ashes carried over from the furnaces, and a man-hole with door for inspection of the stack and removal of the ashes is necessary, and is usually provided. The flues must be lined throughout with firebrick, and they should also be provided with man-holes for the same purpose as that in the stack.

Dampers should be fixed at the ends of the flues where they enter the stack, so that the latter may be inspected or ashes removed without serious discomfort to the men. The internal area of both the flues and the stack should be sufficient to readily carry off the gases generated, or back draught may take place, resulting in serious inconvenience and probably an immoderate consumption of fuel. As the erection of a stack is a costly matter, it should be large enough to allow of considerable extension of the steam plant.

After completion the fire should not be lighted, if it can be avoided, for two or three months at least, so as to allow the brickwork to become dry. In order that the flues may be kept as short as possible, the position of the stack relative to the boilers should be carefully considered, having regard to future extension. When it is intended to extend a rank of boilers to some considerable length, it may be advisable to erect the stack in a position as nearly the centre of the proposed rank as possible, so that on completion the gases from one half will flow into the stack in one direction, and from the other half in the opposite direction.[1] In this case the stack should be divided in the centre by a firebrick wall carried to a height of twenty or thirty feet.

Engine House.—The engine and dynamo house should immediately adjoin the boiler house and run parallel to it, being separated only by a substantial wall, so that the steam pipes may be as short as possible. A travelling crane (capable of lifting the heaviest weight ever likely to require moving) should be provided which will run the whole length of the building over the machinery, and may be driven either by hand or power. The piers

[1] As is indicated in figs. 2 and 4.

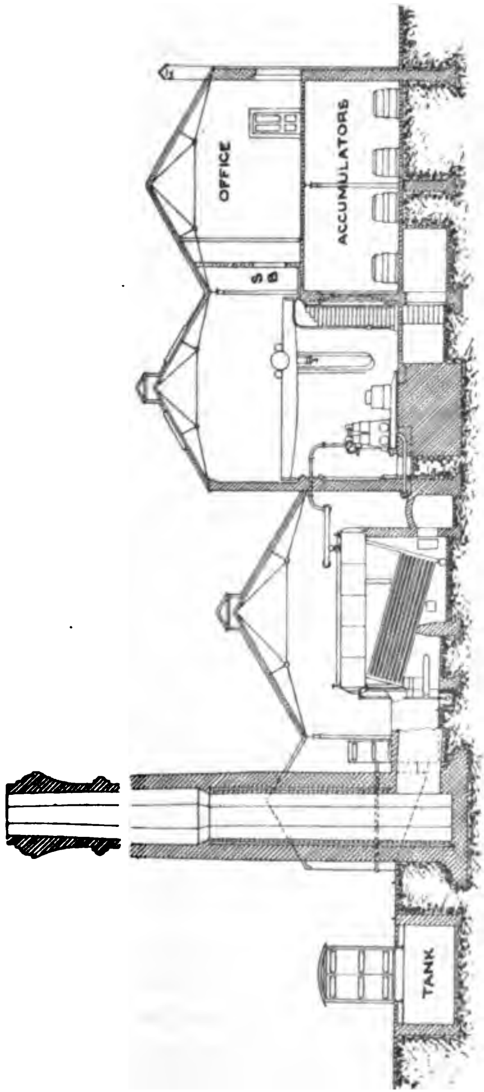


Fig. 3.

supporting the rails for the crane should be bonded with, and form part of, the main walls.

The roof should be high enough to permit of any part of the machinery being carried directly over the plant. Plenty of top light should be provided, but the skylights must be watertight, as leakage may be a serious matter if the water chance to fall upon the dynamos or other electrical plant. Condensation gutters should be fixed to prevent condensed water falling on the machinery. As much ventilation as possible should be allowed in the roof, but it should be under control.

The floor may be of concrete, York stone, blue brick, red tiles, wood blocks, or other durable material. Wood-block flooring is probably the most suitable, and, although expensive, is doubtless cheaper in the end. It will stand hard wear and does not produce grit. If stone, brick, or concrete is used, all high-tension terminals, collectors, &c., must be rendered inaccessible to the workmen.

Prevention of Vibration.—Every reasonable precaution should be taken to prevent the transmission of vibration to adjoining property. The footings of all the walls should be carried down below the engine and dynamo foundations. The latter should be entirely isolated from the walls and from each other, and when the subsoil is of gravel or sand it is probable that no further precaution will be necessary.

When clay forms the subsoil it will be found advantageous to excavate some two or three feet in the form of a tray, and fill in with shingle or sand, upon which the foundations of the machinery can be built to a height of, say, seven or eight feet, the bottom being wider than the top for stability.[1] Joists of wood or steel can be

[1] Lead and rubber seatings and bushings have been used in numerous instances with success, where all other attempts to reduce vibration have proved futile.

laid on pads of rubber or felt across the trenches thus formed between the beds and the floor laid above. These trenches or passages will be convenient receptacles for the steam and exhaust pipes in the case of the engines, and for cables in case of the dynamos, and if the floor above consists of removable sections, or if trap-doors are provided, inspection becomes very simple, and no ladders or steps are necessary, as is the case when pipes are fixed overhead. The advantage of being able to get at a steam pipe without a ladder in order to pack a joint or effect repairs can only be fully appreciated by those who have tried both ways.

Battery-room.—The accumulator or battery-room should be isolated from all other parts of the works, more particularly from those rooms containing machinery, instruments, or other metalwork, as the gas and acid spray given off from the cells are very corrosive.

The size of the cells should be decided upon before the room is planned out, so that proper space may be left between the ranks for inspection as well as for removal and replacement of the plates and cells when required.

All woodwork must be protected with acid-proof paint, several coats of shellac varnish, or paraffin, and all necessary metalwork must likewise be protected.

The walls can be finished smooth, and painted with acid-proof paint, so that they may be periodically cleaned, and any condensed acid spray removed. Proper ventilation is essential in order to remove the gas, &c., or working in the room would be injurious to health, if not impossible.

The sectional view of a station with accumulator-room is given in fig. 3, and the corresponding plan in fig. 4.

CHAPTER IV

PRICE AND METHODS OF CHARGING

WHERE a general supply of electrical energy is provided in any area, any one within that area is entitled to a supply on the same terms as any one else,[1] and no undue preference must be shown to any consumer,[2] but if the charges made for energy be not paid, supply can be discontinued.[3] The prices charged must not exceed the maximum stated in the Schedule to the provisional order, but an agreement may be entered into with any consumer as to price and mode of charging, and the undertakers may require any consumer to pay a deposit, or otherwise give security for payment of charges due from him. The charges may be based upon the quantity of electrical energy supplied, or by the quantity of electricity contained in such supply (i.e. coulombs or ampère-hours), or by any other method which has been approved.

In practice it is necessary to make a general fixed charge per unit, or to adopt some scale which will be equally just and fair to all classes of consumers; and the method finally decided upon must be applicable to the public generally, and not confined to any individual or class. From the undertakers' point of view it is important

[1] Elect. Lighting Act, 1882, Section 19.

[2] *Ibid.* Section 20.

[3] *Ibid.* Section 21.

that the revenue should equal the gross cost of maintaining the service of supply, plus a percentage for depreciation and profit in the case of companies, and for interest on and repayment of capital as well as depreciation where the works are in the hands of a local authority. As a general principle, the charges made should be in inverse proportion to the value of a consumer to the undertaking as a source of profit, and not merely as a source of revenue. A small consumer may be more profitable or less costly to supply than another with a larger bill, but shorter hours, the latter having a very much higher demand used for fewer hours annually. A demand must be encouraged to be profitable, and this requires some stimulation and not a little ingenuity to put the new conditions under which the business is conducted before the public, so that they may see that where they are, in the true sense, good customers to the works they will reap a corresponding benefit.

Undue preference may be roughly defined as giving specially favourable terms to individuals which are not made applicable to other consumers of the same class or bearing similar relationship to the supply. Undue preference is not shown by giving all consumers advantageous terms who have higher load factors than others. Thus a scale of rates per unit diminishing as the annual load factor increases or with the number of units consumed annually is a fair and equitable arrangement which is adopted in many instances.

Application Forms are frequently termed "Contract or agreement forms." Any person intending to make use of electrical power has to serve a notice upon the suppliers of electricity, stating the premises where the supply is desired, the maximum power required, and the date when

the supply is wanted. In this document provisions are generally inserted requiring the intending consumer to comply with the wiring rules of the undertakers, and notice appears thereon of the charges in force for electrical energy, and the rentals at or conditions on which meters are let out on hire. It may be pointed out that by the terms of the Acts a consumer is not necessarily bound to sign an agreement, it is sufficient if notice be given to the undertakers requiring them to supply.

From the application forms received the "consumer's register" is entered up, each consumer being given a number, usually that in consecutive order of receipt of such forms. A curve showing "lamps applied for," together with "lamps connected" and "maximum demand" on the station from day to day, shows at a glance what effect the increasing connections have upon the load.

Inclusive Rentals and Contracts are the simplest methods of charge. The practice of the first electricity supply companies was to levy an inclusive rate per annum based upon the number and candle-power of the lamps installed. A modification of this was to make a yearly rate of a stated sum per lamp fixed.

These methods are obviously primitive and unsatisfactory, and would be so in any commercial transaction, but when electrical energy is the commodity sold they are even more so than at first sight might appear. That a loss to the undertakers was well-nigh inevitable has been proved by the discontent invariably accompanying a change to the use of meters. Thus, to make the lump sum per annum system pay would mean an excessively high figure being settled upon, or an interest in the success of the electricity works being held

by the consumer to prevent his using electricity wastefully.

Public street lighting can, however, be successfully met by a contract price per annum, as a schedule of lighting and extinguishing may be arranged, and the turning on and extinguishing at fixed times be left in the hands of the contractors.

For special purposes the fixed rental system is being exploited by certain undertakings in this country. Two examples of its successful employment are, arc lamps in shops in Ilford and motors for church-organ blowing in Brighton. In each of these instances the hours of use are fixed, and the power required is readily determined and kept at about a certain definite amount, so that an annual charge of £5 can be made to cover all costs. To check the use made of the supply electrically controlled, clock meters are installed. These do not run unless current is switched on, the readings showing the number of hours during which the arc lamps or motors have been in operation. The charge covers an average annual use based on the probable number of hours supply will be required. This is a minimum, any extra duration being paid for *pro rata*.

Metered Supply removed many of the objections from both the point of view of the supplier and the consumer to the fixed rental method of charge. By the use of meters the consumer only pays for what he consumes, and the suppliers receive a return for all they sell.

Many years elapsed before reliable meters for either continuous or alternating currents were put on the market. When such were forthcoming the only objection offered to their adoption was the considerable outlay incurred in providing them, and it remained to be seen whether the

additional returns warranted the change. The cost was covered by requiring the consumer to pay a rental, or to hire the meter to measure his consumption from the suppliers. It was found after a short trial that the generating plant was run at a better load factor, and that a given kilowatt capacity installed was capable of supplying a larger number of lamps connected than before. A proof of this was a station which at first was run on fixed rentals, showing over half the lamps connected alight at one time; meters were afterwards put in and the proportion fell to one-third, the revenue per lamp connected at the same time increasing considerably.[1] Further than this, the principle of charging on the basis of lamps fixed must necessarily tend to keep down the number the consumer instals; whereas by charging solely for the energy consumed, he is free to put in as many as he pleases, and encouraged to use them liberally, knowing that they are no expense unless used, and then only in proportion to the benefit obtained.

Meters give indications of either the quantity of electricity or the quantity of energy consumed. A charge is then made per ampère-hour or per unit. The meter is inserted in one of the service lines, and is generally fixed and maintained by the undertakers.

The rental charged for meters varies in different parts of the country. The average quarterly hire is from 1*s.* to 2*s.* 6*d.* for a 2 k.w. meter. It is customary to increase this figure for larger meters, the largest sizes being often charged at 10*s.* per quarter. Where the supply has been at work for some years, and the financial results are encouraging, there is no doubt that the abolition of meter

[1] Address to the North-Western Electrical Association (U.S.A.) by Mr. G. L. Cole, Jan. 1895.

rents tends to further popularize the business, and those stations which have taken this step have found that the concession is appreciated by the public.

Supply meters are legal instruments only when they have been certified by an electric inspector to be of a construction and pattern approved by the Board of Trade; to be correct meters; and to have been fixed and connected to the service lines in a manner approved by the authority charged with the appointment of the electric inspector. The type of meter must receive approval by the Board of Trade, who conduct lengthy and exhaustive tests before giving such approval.[1] Laboratories for testing meters have been established in the City and the County of London, and by several Corporations who are not themselves undertakers. Consumers who doubt the correctness of meters on their premises have the right to appeal to the electric inspector of such local authorities for an independent test, the fee being paid by the consumer if the result be against him, and by the undertakers if the meter be found inaccurate. Meters require to be arranged so that they can be double-sealed; the case and working parts being sealed after testing, so that the mechanism cannot be tampered with, and the terminals being under

[1] The Board of Trade has approved of the following types:—

Alternating Current.		Direct Current.	
Quantity Meters.	*Energy Meters.*	*Quantity Meters.*	*Energy Meters.*
Shallenberger.	Aron.	Ferranti.	Aron.
	Shallenberger.	Hookham.	
	Westinghouse.	Bastian.	
	Hummel.	Long Schattner.	
		Thomson-Houston.	

This list may be extended at an early date, as several other types are under test and may be approved shortly.

a separate case, or part of the principal case which does not expose the gear, and which is fastened securely by the undertakers when the meter has been fixed in position.

Consumers' meters are essentially watt-hour integrators. Preferably they are of a type with vertical dials showing directly the units passed through. Otherwise the reading of the dials has to be multiplied by a "constant." If ampère-hour meters are used, the quantity of energy is taken as the product of the quantity of electricity and the "declared" pressure at the consumer's terminals, on the assumption that this is maintained constant at the declared value. On constant current series circuits integrating volt-hour meters have been used.[1]

Energy meters integrate the supply pressure by virtue of a shunt coil, and as this is continuously connected to the mains, the energy wasted therein may represent a serious loss taken throughout the year. Meters with shunts start more freely than those without, and the loss is more than made up by the readiness with which the energy used by single lamps is recorded.

Before erecting a meter on a consumer's premises it should be tested for starting current, voltage drop in the series coil with full load current, accuracy at $\frac{1}{10}$, $\frac{1}{2}$, and full loads, insulation from circuit to frame (and if provided with a shunt-coil, insulation from shunt to series, shunt to frame, and watts lost in shunt), and stopping current. Shunt meters sometimes "creep" or run on the shunt alone, if badly adjusted.

For continuous currents various types of electrolytic meters have been extensively adopted during the last few years, as they are cheap, and register the consumption at

[1] By Mr. Arthur Wright at Brighton. *Electrician*, vol. xx. p. 128.

low loads without difficulty. They have the objections that the loss of pressure across them is rather high, and they cannot be checked or calibrated as easily as mechanical types, while in some of the older patterns the terminals or electrodes had a habit of burning off. The makes in general use are the Schattner, the Bastian, and the Wright. They are, of course, ampère-hour meters, and the consumption in units is based upon the assumption that the voltage of supply is constant.

Aron or differential clock meters have been employed for both alternating and direct currents, and have the advantage of a flat curve, so that if the meter is correct at any load it must be accurate at all others throughout its range, which is determined by the heating of the coils only.

The remaining forms of meters are of the motor type, with magnetic or fluid brake. These are very numerous, and particulars of their construction are to be found in the various treatises dealing with this portion of the subject, references being given in the Bibliography and Appendices at the end of this volume.

A Minimum Charge is provided for by statute. So long as electricity was regarded as a novelty and luxury, and the average price per unit was more than 4*d.* or 4½*d.*, there was a tendency for consumers to require a supply without giving an adequate return. Thus any one in an area scheduled for supply could demand a supply, and the undertakers had no option but to accede even if the necessary mains cost £20 or £30, and the supply was only taken for two or three lamps, the revenue from which might only amount to 10*s.* or 15*s.* per annum. To prevent unfair dealing, the Legislature have seen fit to empower undertakers to charge a minimum sum per quarter; this

varies from about 10*s*. to something like £1, generally being equal to twenty units per quarter at the maximum rate of charge authorized.

This figure did not altogether prevent an injustice being done to undertakers by persons running private plant who required a supply from the street mains, which was, however, actually used only in the event of a breakdown in the private supply. The undertakers had at all times to be ready to supply, but, being very seldom called upon to do so, they received an infinitesimal return upon the capital invested.

This hardship will be removed by the provision in Lord Wolverton's Bill laid before Parliament in 1905, in which a "stand-by clause," as amended by the Lords Committee, provides that a consumer "shall not be entitled to demand or continue to receive from undertakers a supply of electricity for any premises having a separate supply, unless he agrees to pay such minimum annual sum as will equal a reasonable return upon the capital expenditure and will cover other standing charges incurred by them in order to meet the possible maximum demand for those premises."

The Lighting Hours with different classes of consumers vary enormously. An approximate idea of the usual hours during which electric light is used in the more important classes of customers is given below.

Class of Consumer.	Hours per annum.
Street Lamps for Public Lighting. From dusk to daylight	3,764
Restaurants, Tobacconists, Hotels, and Clubs. Kitchens, Basements, &c. From dusk to 12.30 a.m.	2,109
Hotels and Clubs Reading and Smoking Rooms. Hall and Staircases (until midnight)	1,929
Theatres, Music Halls, &c. From 7.30 p.m. to 11.30 p.m.	1,349
Shops and Hotel Drawing Rooms. From dusk to 10 p.m.	1,197

Class of Consumer.	Hours per annum.
Hotels, &c., Dining Rooms	900
Hotel Coffee Rooms	600
Warehouses, Shops, &c. From dusk to 8 p.m., and from 7 a.m. to daylight	512
Hotels, &c., Bed Rooms	450
,, ,, Billiard Rooms	300
Public and other Offices. From dusk to 7 p.m.	284

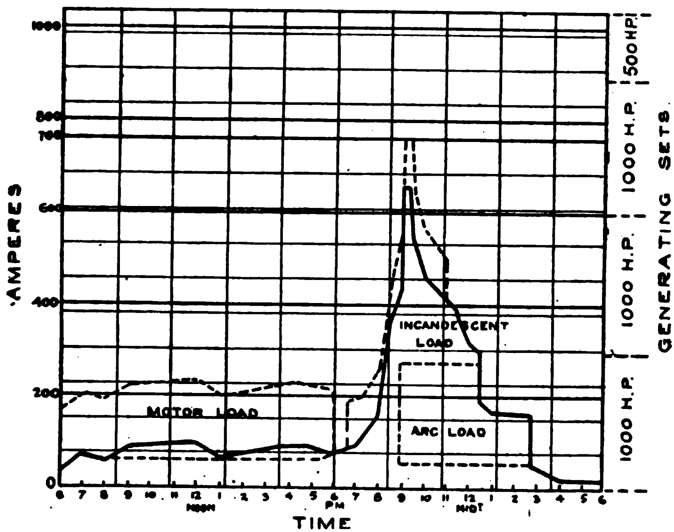


Fig. 5.—Summer Load Curves.

As each class has a more or less definite period of consumption, attempts have been made to charge a fixed rate per unit for each class, but this has been found liable to misconception on the part of the public, and has fallen into disuse.[1] The hours of lighting per month for general lighting of premises open to natural light is shown in the

[1] Although a system very similar to this has been proposed by the *Electrical Engineer* and adopted by Dundee, April, 1905.

next table. This is an average for England, and, for the metropolis and large cities subject to fog, must be increased by about 25 per cent. for shop and domestic lighting.

Time of Day or Night	Number of Hours of Lighting in each month, from dusk to time given in first column of Table.												Yearly totals of hours from dusk to time stated in first column.
	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	
4.30 p.m.	...	...	...	...	...	...	...	...	...	...	...	...	...
5.0 ,,	...	...	...	...	...	...	...	...	...	...	...	12	12
5.30 ,,	9	...	...	...	...	...	...	...	...	...	17	27	53
6.0 ,,	25	11	...	...	...	...	...	...	...	11	32	43	122
6.30 ,,	40	25	...	...	...	...	...	...	...	26	47	58	196
7.0 ,,	56	40	...	...	...	...	...	...	10	42	62	74	284
7.30 ,,	71	54	21	...	...	...	...	...	25	57	77	89	394
8.0 ,,	87	69	36	...	...	...	...	10	40	73	92	105	512
8.30 ,,	102	83	51	23	...	...	...	25	55	88	107	120	654
9.0 ,,	118	98	67	38	19	...	15	41	70	104	122	136	828
9.30 ,,	133	112	82	53	35	18	30	56	85	119	137	151	1,011
10.0 ,,	149	127	98	68	50	33	46	72	100	135	152	167	1,197
10.30 ,,	164	141	113	83	66	48	61	87	115	150	167	182	1,377
11.0 ,,	180	156	129	98	81	63	77	103	130	166	182	198	1,563
11.30 ,,	195	170	144	113	97	78	92	118	145	181	197	213	1,743
Mdt. ...	211	185	160	128	112	93	108	134	160	197	212	229	1,929
12.30 a m.	226	199	175	143	128	108	123	149	175	212	227	244	2,109
1.0 ,,	242	214	191	158	143	123	139	165	190	228	242	260	2,295
1.30 ,,	257	228	206	173	159	138	154	180	205	243	257	275	2,475
2.0 ,,	273	243	221	188	173	153	170	196	220	259	272	291	2,659
2.30 ,,	288	257	237	203	198	168	185	211	235	274	287	307	2,850
3.0 ,,	304	272	252	218	...	...	201	227	250	290	302	322	3,004
3.30 ,,	319	286	268	233	...	...	...	242	265	305	317	338	3,140
4.0 ,,	335	301	283	248	...	...	...	258	280	321	332	353	3,278
4.30 ,,	350	315	299	263	...	...	...	...	295	336	347	369	3,399
5.0 ,,	366	330	314	...	...	...	...	...	310	352	362	384	3,506
5.30 ,,	381	344	329	...	..	...	...	...	...	367	377	400	3,596
6.0 ,,	397	359	...	...	...	...	...	...	...	383	392	415	3,673
6.30 ,,	412	373	...	...	...	...	...	...	...	...	407	431	3,733
7.0 ,,	428	...	...	...	...	...	...	...	...	...	...	446	3,764
7.30 ,,	...	...	...	...	...	...	...	...	...	...	...	...	...
	428	373	329	263	198	168	201	258	310	383	407	446	=3,764 hrs.

Owing to the peak produced on a station load-curve by the coincidence of public and private lighting the plant installed is fixed by the maximum load, and in arranging tariffs the main object kept in view is to create a bye-use of electrical energy which will give useful employment to the machinery when not employed for lighting. During the summer the motor load does not top the peak, and

therefore is of the greatest assistance at the time it is most wanted (fig. 5). In the winter it adds to the peak, but does not interfere with the theatre load (fig. 7). The difficulty of equalizing the summer, autumn and winter load (figs. 5 and 6) remains, and there is no means by which this can be got over. In inland towns the maximum peak occurs at or about Christmastide;

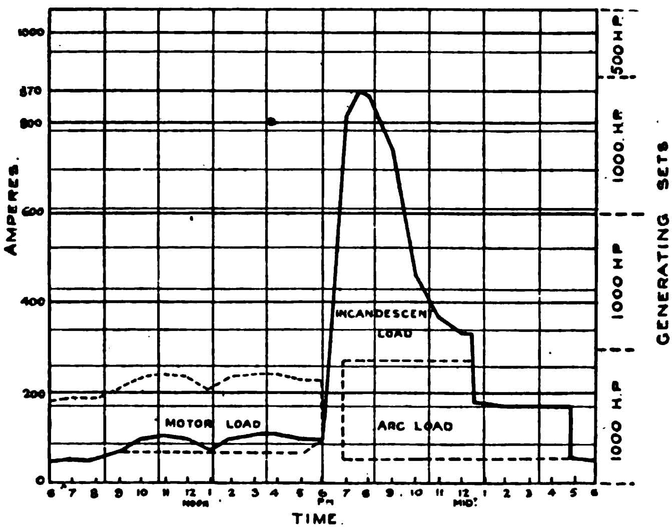


Fig. 6.—Autumn Load Curves.

in seaside resorts it coincides with the holiday season in the summer, and increases the trouble the engineer has to face, as the peak occurs at a time when the duration of lighting is short, and the units sold with greatest load are less than if the same maximum took place in the depth of winter.

A Uniform Price requires little explanation. When supply is given by meter the quantity of electrical energy

taken by the consumer may be read monthly, or even fortnightly for the purpose of the undertakers, but the accounts are usually sent in quarterly. A card is left near each meter on which readings are entered as they are taken, together with date and name of person making the entry. The quarterly accounts show the number of units consumed and the price charged per unit, and from

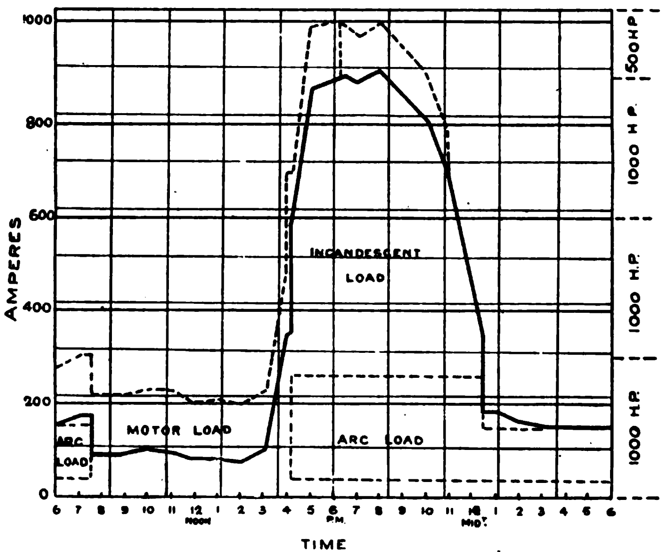


Fig. 7.—Winter Load Curves.

these the bill is made up. The price per unit may be anything up to 8*d*., and the total cost of the supply is therefore directly proportional to the consumption. The flat rate of charge or uniform price is readily understood by the public, and provided that it is low enough to insure reasonable satisfaction, there is in it, at first sight, all that is required. Electricity supply came into the field late in the day, when gas was almost

universal. The success that attends its introduction, therefore, largely depends upon price, as this is the most potent factor in determining the extent of the demand created.

It is almost impossible to bring down the cost of electrical energy to a figure which would encourage the bye uses of electricity if a uniform price were insisted upon. The conditions which govern the cost of production are peculiar to the business, and theoretically it is opposed to the logic of facts to adopt this method. What is aimed at is a means whereby the gross cost of energy to any given good customer may be minimized, and this can only be effected by a scale which takes into consideration the relative expenditure incured in generation and distribution, use of capital, and all other outlays.

The recommendation of a fixed rate of charge is its simplicity, and some engineers consider that the interests of the greatest number of consumers are best secured by a system of uniform charge, rather than by one which gives advantage to a limited number of consumers at the expense of the rest. Thus it was found desirable in Liverpool, after four years' trial of a sliding scale, to abandon it, and to adopt in its place a uniform rate of charge.[1]

It must not be forgotten that each consumer represents a factor in the competitive war between rival illuminants or alternative means of factory-driving, and a coalition of interests has to be effected whereby the good-will of the majority is secured without losing the advantages afforded by the valuable custom of the minority. The majority, which includes in towns the large early-closing shops

[1] A. B. Holmes on "The Public Supply of Electrical Energy; its cost and price." *Trans. Liverpool Eng. Soc.* vol. xv. p. 92.

with heavy lighting bills, may not be such good customers from the point of view of load factor and steady demand as the minority, but by reason of their numbers and commercial importance they carry weight in any argument that may occur, and are able to make their views known. On the other hand, the consumers represented by the minority may take as many units collectively as the majority, and therefore the engineer is inclined to pay attention to them as his best customers.

Discounts and Rebates in electricity supply follow the ordinary business principle that "a discount should be given on taking a quantity." The mode of calculating the discount is, however, an important point, as it must be remembered that besides the "quantity" (or number of units taken per annum or per quarter) the "rate" at which that quantity is consumed must also be considered. In the absence of storage on a large scale and analogous to the way in which gas is treated, the latter factor is the all-important one in deciding at what cost the units are generated and distributed.

The first attempt to encourage the large consumer was to give a fixed percentage discount on all bills for over a certain number of units per annum, this being deducted from the last quarterly account in each year. This was varied by increasing the discount in proportion to the face value of the bill for energy. That these methods are definite but irrational clearly follows, since the number of lamps fixed or maximum current taken have no influence upon the amount so deducted. Where a discount is offered to consumers who use more than a stated quantity of electrical energy irrespective of the rate at which that quantity is taken, small consumers consider they are unfairly treated.

Reduced charges affect the lighting portion of the business to an enormous extent. No mere change in the price charged per unit will induce people to use electricity when not wanted; but until electric lighting becomes as general as gas-lighting there is a large field to be worked in competing with gas. Thus the price asked and method of charging will affect the public demand for electric lighting. If the conditions are unfavourable, they will only make a change where a direct benefit can be shown or where the advertisement will pay; as an example, we may cite the extended adoption of window-lighting. The first consumers to be connected are those who, as a rule, take a large current for single premises, such as places of amusement, high-class shops, hotels and such-like. The number of lamps connected per consumer is high, and the cost of connection proportionally low. In many cases, however, the revenue per ampère demanded is less than that anticipated, and below that which premises of less importance yield. As the number of consumers increases, a greater variety of classes are included; their hours of maximum demand are diverse, and lamps per consumer is a ratio that falls. While the units sold per lamp is rather better than before, as the hours are greater, the revenue per lamp may fall, but it shows an increased profit. The cost of connecting such consumers is greater per kilowatt than before, as more meters and services are required, and the connection cost per kilowatt demanded on the mains tends to increase with the growth of the supply.

Hopkinson's ideal method was a fixed charge per quarter proportional to the greatest rate of supply the consumer will ever take, and an additional charge by

meter for the actual consumption.[1] He was instrumental in obtaining the insertion of a clause to this effect in provisional orders many years ago. The basis of his reasoning may be briefly summarized by stating that on the one hand there are expenses which are quite independent of the extent to which an undertaking of electricity supply is used, and, on the other, expenses which are absent unless the undertaking is used, and which increase in proportion to its use. There is a fixed charge, for example, for the use of capital, and for maintaining against the assaults of time the things in which the capital is embodied. Other expenses connected with station plant are, for the greater part, proportional to the use made of it.

Sliding scales are therefore based upon the fact that whereas in some cases the service which the undertaker is required to render can be performed at a time selected by the undertaker, in others it is called for at a time selected by him to whom the service is rendered; and as electricity supply· is most forcibly a case falling in the latter category, the charge made to consumers for supply should bear some relation to the cost of rendering the service. Many things can be made at convenient times, when labour and raw material is cheap, stored or retained in stock in large quantities at a low cost, and kept till they are wanted and they can be disposed of to meet a remunerative demand. Electrical energy is a commodity which cannot be so produced and stored, but must be generated and distributed at the moment the person supplied requires it. That is to say, no more plant has to be provided to give a steady supply day and night than

[1] *Trans. Junior Eng. Soc.* Presidential Address by the late Dr. John Hopkinson, 1892.

is necessary to give a supply for one hour out of the twenty-four.

What is most wanted is a constant load throughout the twenty-four hours of the day, and every day in the year. No business achieves this; each and every one has a period of brisk demand and other times of slackness, but few are so unfortunately placed that their busy period is only an hour or two a day. The conditions are more onerous in electricity supply than in any other. Water supply, gas supply, hydraulic power, the production and issuing of daily newspapers, railway traffic, and other callings may be cited as analogous examples, but their load factors are much more favourable.

Obviously the undertakers cannot exercise any control over the period of demand or the amount of power or energy taken, and therefore all they can do is to devise scales of price which encourage the consumer to take power at the right time, from their point of view, and dissuade him at other times. Examples are given in fig. 8. Natural conditions cause a demand to exist at what the engineer considers the wrong time, and no artificial stimulus is therefore then necessary.

Mr. Arthur Wright has applied the principles laid down by Dr. Hopkinson to the actual accounts of a large station,[1] in full working order, and by analyzing the figures for a year found the standing-by charges to amount to £17 9*s.* per kilowatt, and the running costs to ·71*d.* per unit, or, roughly speaking, £18 represented the yearly expenditure entailed in having to be always ready to supply one kilowatt, the cost of this taken for one hour

[1] "The Cost of Electricity Supply," read at the London (1896) Convention of the Municipal Electrical Association. Also Presidential Address M.E.A. 1901, and *Journ. Inst. E.E.*, December, 1901.

being about ¾*d.* As the maximum demands of different consumers were not coincident, the maximum load on the plant being only 60 per cent. of the aggregate individual demands, the figure of £12 was taken as the yearly cost per kilowatt and 8*d.* per unit for energy taken at the rate of one hour per day. Dividing the charges up into basic expenses, connection costs, and demand costs for the station above referred to; the first

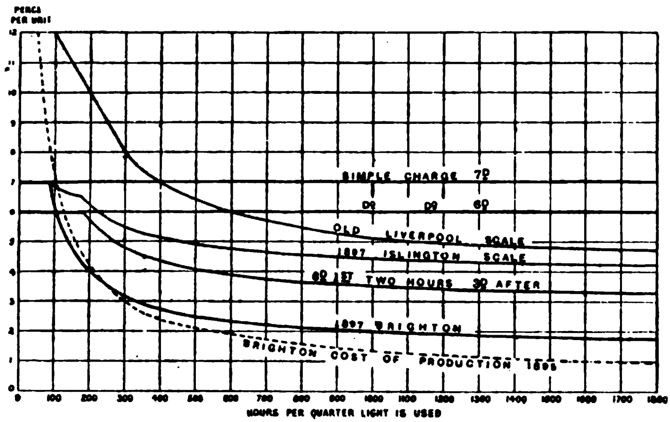


Fig. 8.

were 6·3 per cent., the second 11 per cent., the demand cost 66·4 per cent., and the running costs 16·4 per cent. of the total yearly expenditure. These figures have since been greatly improved, but they serve to illustrate the intrinsic difference between the standing charges and running costs.

Different classes of consumers have very varying periods and times of demand. Some will add to the maximum maximum, but increase the area of the load diagram but little; others will have some effect in

enlarging the area, but will not raise the peak appreciably, while a third class will take a large quantity of energy without affecting the maximum maximum, but will tend to raise the average maxima up to the level of the greatest maxima.

For the purpose of analysis consumers may be divided into four classes:—

(*a*) Those connected during a year for whom plant had to be provided beforehand, but whose revenue could not be expected to pay off their proportion of standing charges. Say 8 per cent. of the total revenue coming from these.

(*b*) Consumers using maximum demand less than 365 hours per year. Say 10 per cent. of the total revenue from these.

(*c*) Consumers using maximum demand from 365 to 550 hours per year. Say 12 per cent. of the total revenue from these.

(*d*) Consumers using maximum demand over 550 hours per year. Say 70 per cent. of the total revenue from these.

The results for classes (*a*), (*b*) and (*c*) may show a loss upon the supply, and this has to be recouped by the profitable long-hour consumers.

A fixed charge on demand installed plus rate per unit is a method in force in Manchester, where, on Dr. Hopkinson's principle, a fixed yearly sum is charged per kilowatt capacity of lamps or consuming devices installed, and this has to be paid by the consumer, whether he makes much or little use of the supply. It covers the costs of the undertakers in being ready to supply. In addition the quantity of energy consumed is charged for at a low rate approximating to the cost of generating. The rates were formerly a fixed charge of £7 per annum per kilowatt installed by the consumer, and a variable charge of 1¼*d.* per unit for the electrical energy taken. This was offered as an alternative to a fixed price of 5*d.*

A fixed charge on measured demand, plus rate per unit,

is an advance upon the foregoing, as it takes into account the actual instead of the possible and problematical call upon the plant by a consumer. An example is a scale introduced by Mr. Leonard Andrews at the time he was in responsible control of the Hastings undertaking. It was based upon a fixed quarterly payment for the maximum number of lamps simultaneously lighted during one quarter, and a fixed price per unit for the metered consumption. The maximum demand was ascertained by an ammeter or demand-indicator calibrated in lamps, a lamp being assumed to require ·35 ampère at 100 volts. On this scale a consumer had to pay a fixed charge of 1*s.* per quarter per "lamp" demanded and a variable charge of 6*d.* per unit for electrical energy taken. The fixed charge worked out to about £6 per kilowatt for each year, and was therefore low, while 6*d.* per unit was a high figure to ask for electrical energy in addition. This scale tended to equalize the amount of the quarterly bills, and, being readily understood by the public, seems to have met with success in the hands of its originator.

In London one local authority now charges 1*s.* 3*d.* per 8 c.-p. lamp demanded, and 2½*d.* per unit consumed.

Sliding Scales are those in which the rate per unit is not an unvariable figure, but depends upon the number consumed per lamp fixed or per ampère of greatest simultaneous demand. The earliest example was one in use many years ago in Liverpool, which is interesting in itself as well as in its results. It had many advantages, but it must be remembered that the figures applied to the supply at a time when the question of price had not been exhaustively dealt with. The tariff was as follows:—For the first 100 hours per quarter of the maximum supply applied for, 1*s.* per unit; for the second 100

hours of the same, 8*d*. per unit; and for all further quantities, 4*d*. per unit. This scale, being based upon the nominal and not the actual demand, must have tended to deter the public from making a liberal use of the new means of lighting.

A similar scale was afterwards adopted by the company now known as the Brompton and Kensington in London, and it appears to have been the first practical attempt to encourage the long-hour consumer. The prices charged were high in those days, and as but few consumers take current for the whole of their lamps and devices installed for over 100 hours per quarter (when the price would fall to 8*d*. per unit) its effect was but little felt.

The demand made by a consumer upon the works, and his installed capacity of lamps, &c., are only synonymous in special instances; more frequently only a percentage of the lamps fixed are in actual use at any one time. But the greater the number fixed, the larger will the revenue probably be, and if this reaches an extreme case, the consumer and the suppliers both benefit under a rational method of charging. It is the maximum actual demand that affects the central station, where plant has to be kept in readiness to meet it.

A maximum-indicating ammeter inserted into each service line will show the greatest power that has ever been taken. It also gives, in conjunction with a supply meter, the average number of hours per day throughout the quarter that the maximum number of units per hour has been maintained. Obviously, the supply meter gives the total units per quarter; the current indicated by the demand ammeter multiplied by the declared pressure of supply divided by 1,000 will give the maximum units per hour taken at any time during the quarter, and then, by

dividing the first quantity by the last, and further dividing the result by 91 (being the number of days in the quarter), we get the average number of hours per day the (maximum) supply has been used.

The maximum demand indicator, or rebate finder, devised by Mr. Arthur Wright is essentially a differential air thermometer, so constructed that it becomes a thermal self-recording maximum ammeter. A small resistance coil or strip of platinoid is wound on one air-bulb of a U-shaped glass vessel, and through this coil the current to the consumer is taken. The double glass tube is filled with a suitable dark liquid, and the other air-bulb has a third glass tube connected to it at a point close to the bulb. As the liquid rises it flows over the weir formed by the junction of the two tubes, and partly fills the third or gauge tube which is closed at its lower end. The scale is read from the bottom upwards. This type can be read with the current flowing, and is easily re-set.

To reset the instrument the tube is tilted outwards and upwards on a hinge at the top, the whole of the liquid then runs back into the U tube and refills it ready for further use. The pressure drop in the coils of the instrument is small, being under half a volt; the power wasted is negligible, being under ten watts; and the apparatus being simple, there is nothing to get out of order or require repair, while the readings cannot be affected by outside influences, and the indicator is practically frictionless.

The terminals are at the upper part of the case (fig. 9), connection being made to the coil by short, flexible conductors; the cables enter through insulating bushes at the side. The insulating base is of ebonite. On one side of the indicating column is a scale of ampères, and on the other a table of the "units to be consumed per half-year

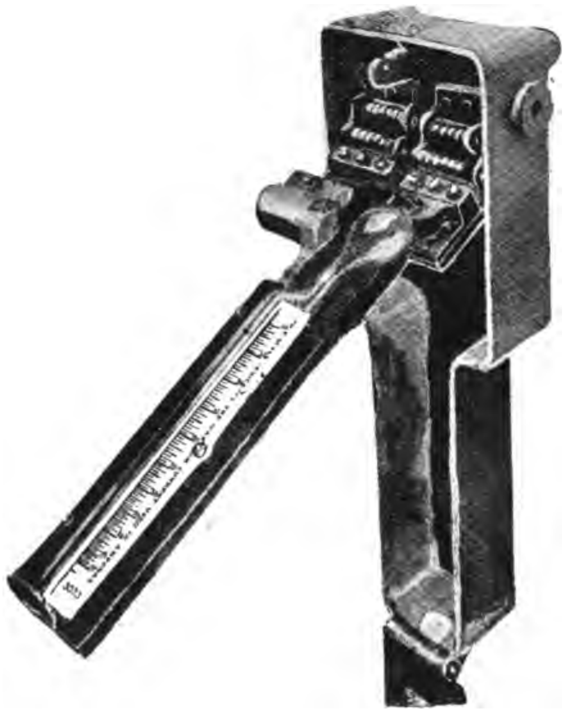


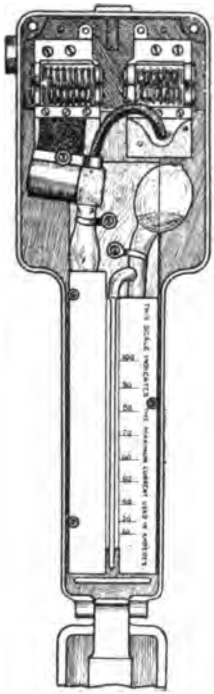
Fig. 9c.

[*To face p.* 85.

or per quarter before the reduced price is charged." It requires about a quarter of an hour for the temperature to reach a state of equilibrium and the liquid to reach its full value corresponding to the current. There are many

CLOSED

Fig. 9a.



OPEN

Fig. 9b.

advantages to be gained by having such means of checking the consumer's current, and the surreptitious addition of lamps to those already fixed cannot take place without the knowledge of the undertakers.

A three-wire indicator is made in which the bifurcation of the middle wire to supply the two two-wire circuits takes place in the instrument, a resistance is inserted in each of the circuits, and the heating-strip connects the ends of the resistances. The reading of the instrument then gives the sum of the maximum currents taken on the two-wire circuits. A magnetic two-wire pattern is made in which a core and solenoid cause the displacement of the fluid by tipping the tube instead of heating it.

Other types of demand indicators are the Wilson, the Schattner and the Fricker. The Wilson can only be used with motor meters having brake magnets. It is a maximum pointer showing the position taken up at highest current by the brake magnets which are suspended and free to move against the action of a spring. As the meter runs the disc tends to drag the brake round with it in the direction of its rotation, the distance moved being proportional to the driving current and inverse to the power of the restraining spring. The Schattner indicator has a soft iron core sucked into an ammeter solenoid and carrying a right-angled tube filled with glycerine, and containing a number of steel balls. As the balls nearly fit the tube on being tilted up by the current they slowly fall over into the second limb, the number going over measuring the maximum current. The Fricker indicator has a vertical glass tube with a bulb at each end, the lower bulb is heated, and the gas it contains is driven upwards through a drop of mercury forming a gas valve in the bottom of the upper bulb. On the instrument cooling the contraction of the gas in the lower bulb draws a thread of mercury downwards from the globule, the length this mercurial thread extends from the globule giving an indication of the demand.

Scales based on the maximum demand aim at recouping the undertakers in the charge made for the first one or two hours per day consumption, after which a materially reduced price is charged. At Brighton, for instance, the *maximum demand* is taken as the mean of three readings of the demand indicator in each half year, and the rebate is calculated on this, and not per quarter. The price has come down to—

> 7*d*. per unit for the first hour per day of the *maximum supply demanded*, and 1*d*. per unit for all over this consumption.

In some cases the "maximum demand" is the reading of the demand indicator, which is set once a quarter, and the rebate is given on each quarter's account.

Yet another way of using the maximum demand is to give a discount somewhat as shown in the following table:—

Maximum demand.	DISCOUNTS.				
	5 % (700).	10 % (1,000)	15 % (1,200)	20 % (1,500)	25 % (1,800)
Ampères	*If the following minimum quantities are consumed:—*				
1	77	110	132	165	198
2	154	220	264	330	396
3	231	330	396	495	594
4	308	440	528	660	792
5	385	550	660	825	990
&c.	&c.	&c.	&c.	&c.	&c.

Pressure of supply = 110 volts: equivalent hours per annum in brackets.

In the Potteries two undertakings just started charge respectively 7*d*. for 91 hours quarterly (i.e. 1 hour daily) and 2*d*. after, and 7*d*. for 69 hours (i.e. ¾ hour daily) and 2*d*. after; while Hanley has reduced from 6*d*. for 150 hours (i.e. 1 hour 40 mins. daily), and 3*d*. after to initial period of 91 hours quarterly.

Non-peak rates are allowed to consumers who will undertake not to encroach upon the peak time. One of the modifications introduced on the sliding scale at Brighton has been the cutting out of the demand indicator during the summer months whereby such customers as the pier have obtained their supply at the follow-on rate of 1*d.* per unit. Another example is the motor tariff at Glasgow, long-hour consumers paying 1½*d.* per unit in the year, for 1,277 times their hourly maximum consumption and ¾*d.* after, while short-hour customers who so arrange their demand that no current is taken by them during the hours between 3.30 p.m. and 6 p.m., in the months of November, December and January, are allowed a special rate of 1*d.* per unit.

Filling up the Load Curve is the object of sliding scales, by encouraging the profitable long-hour consumer without at the same time discouraging the well-to-do individual who desires to wire his premises throughout. Any scale which embodies a fixed charge per lamp fixed, evidently tends to keep down the number of lamps that a consumer is likely to instal. The fixed charge acts as a deterrent to those who would otherwise add to the total revenue of the suppliers, although the revenue per lamp per annum might thereby be somewhat reduced. The demand indicator improves upon this by substituting the maximum actual demand for the greatest possible demand, and thereby operates to flatten the load curve, which is the same thing as increasing the units sold per lamp per annum. But the desirable filling up of the load curve cannot be effected by any scale; to do this requires the addition of a load which is independent of climatic conditions or the recurrent periods of darkness and natural light. A day supply is fostered by the custom of charging

energy at half price or less during the daytime. The only difficulty is to differentiate between the daytime and the daylight hours. Some consumers are of so little benefit to the suppliers of electricity that it would be actually advantageous not to supply them. There can be no advantage in merely increasing the station load if the revenue does not increase in such a proportion that all the increased costs are met. In large towns many of the better-class shops shut at comparatively early hours, and it will be found that to take their custom is to actually supply electrical energy at less than the total cost incurred.

Motive power occupies a rather distinct position. It was recognized in very early days as likely to be of importance, and as a motor is probably used for several hours daily, and is principally run during the hours when the lighting load is negligible, many attempts to extend this field have been made. Such supply, if taken on a reasonable scale, creates a day demand of quite a different kind to that of lighting, but the price charged must be limited, for electricity has then to compete with steam and gas power. If, however, the motor load curve overlaps the lighting load curve, the great advantage of this class of demand disappears, and it would be unremunerative to supply current for any purpose much below the general evening price, as a portion of the generating and distributing plant has now to be set aside, as it were, for the purpose of this supply.

Current for motors is offered at a reduced rate, being registered by a separate meter, on the assumption that in any case a large discount would be given, and it might as well take effect in the stated price. If motors run after the hours of daylight are over, the power supplied should then be charged at full price, but

this is not allowed for on the uniform-charge method. The double meter rent is objectionable to some extent, and the period of demand is of more importance than the class of demand. Where lamps are lighted during the daytime, they are equally valuable, as it is the time at which energy is required that is important to the undertakers, and not the purpose to which it is put.

Meter Time Switches have been devised to differentiate

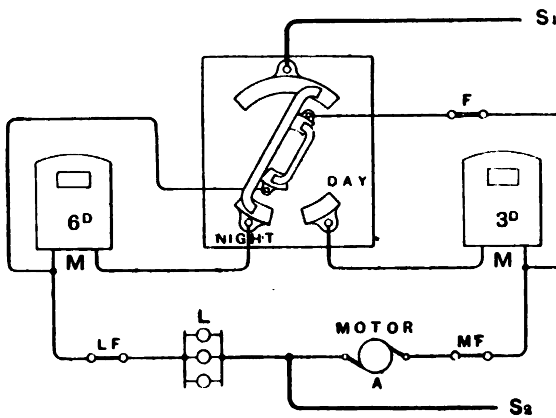


Fig. 10.—"Daylight" Supply Switch.

between merely a day demand and a "daylight" demand.[1] The type designed by Mr. J. T. Baron and shown in fig. 10 is applicable to consumers who take light only, or light and power. The apparatus consists of a two-way and a single-way switch coupled together. Two meters, one for the ordinary price and the other for the "cheap daylight service," are put in and connected as

[1] "The Cheap Daylight Service of the St. Pancras Electricity Supply." *Elect. Review*, vol. xxxi. p. 537.

shown. There are two positions of the switch handle, respectively marked, say, 6*d.* and 3*d.*, and when the handle is in either position the corresponding meter is in circuit. The consumer cannot, however, light the whole of his premises so long as the lower price is charged, but a few lamps may be connected to the daylight supply.

Two-rate Meters controlled from central station were suggested some years ago by Mr. Scott, of Norwich, who brought out an integrating watt-hour meter, the shunt coil of which was normally connected across the consumer's terminals. The inventor proposed to connect the shunt coils across one of the supply mains, and a special meter wire to be laid all over the district, or across two such meter wires, with the object of charging a fixed price per unit combined with variation in the meter registration, which would depend upon the time of the day when current was taken.[1] There are several practical objections to any system which requires additional cables to be laid, and which puts the control of the metering operations into the hands of the staff at the electricity works. In some cases also it is desirable that the meters should give true indications of the units sold, but this could be effected by a double set of dials, one of which registered the units to be charged, and the other the units taken.

Meters with one set of motor and brake mechanism and two counting or integrating trains, with a clock-controlled change-over system from one to the other, are now being manufactured on the Continent.

Kapp's Meter Switch rendered the arrangements self-contained, and still retained, the principle that the period of the day should control the price for electrical energy.

[1] "The Supply of Electricity at Norwich." *Elect. Review*, vol. xxxix. p. 564, 1896.

Mr. Kapp has suggested that a clock could be used to operate a switch which would shunt the meter during the daylight hours, and thereby cause it to run slow by a predetermined amount. One of the forms the apparatus has taken is shown in fig. 11. The main fuse box or consumer's terminals, M F, are connected to the interior wiring, in one of which leads the meter, M, is placed. An electrically driven clock, C, at certain times closes the switch, S, putting the wires R, *r*, in parallel with the

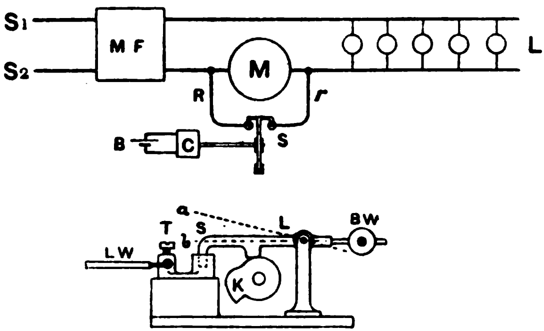


Fig. 11.

meter. The resistance of these wires is such that the current through the meter is reduced to a known fraction of the current being taken by the lamps, &c., L. In the side view, L W is one of the consumer's leads which is brought to the mercury cup, and the switch lever, S L (counterbalanced by the weight, B W), is allowed to fall to the position *b* by the cam, K, so that the meter is shunted during those hours when a reduced price is charged. As the evening comes on the cam, K, is rotated by the electric clock, and raises the lever which breaks the shunt circuit, and the whole supply is metered. Later on, when the cam

has rotated further, the lever drops from the position *a* to that of *b*, and the shunt is again closed.

Wilson's Meter Switch is a modification of the Kapp switch, and is shown in fig. 12. The switching over from one rate to another is done by a rotating disc coupled to a clock which causes it to make one revolution in twenty-four hours. The series coils of compound-wound (or energy) meters are not interfered with; the switch merely inserts resistance in the shunt coil circuit. The relative

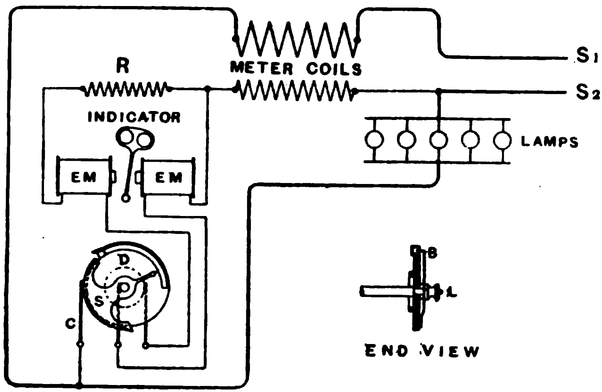


Fig. 12.

positions of the shield, S, the main disc, D, and the driving shaft may be readily adjusted by loosening the binding screw, B, and the lock nut, L, and moving the disc round till the spring, C, falls off on to the shield at any time that has been previously determined. The hands of the driving clock are then moved on to the time when the low rate is to be charged again, and the shield held in position while the binding screw locks both in their proper positions.

A meter switch of this type with two-way contacts is largely used with two independent meters. The main

current coils are in series, and one or other of the shunt coils is connected across the circuit at different times, so that one meter registers day-light, and the other night consumption.

Special Charges.—The only charges the consumer is called upon to pay beyond his bill for electrical energy and meter rent are of a special character. Thus, if his peculiar requirements cause the undertakers to lay an excessive length of service line, he may be called upon to reimburse them this expense. Some station managers make a charge for connecting in the first instance. There is, perhaps, more reason for charging such a fee in every case where the wiring fails to comply with the rules, or where a short circuit on a consumer's premises blows the service fuse. The undertakers are entitled to charge against the consumer the cost of altering meters and services where he increases his demand, but, as he is then ostensibly a better customer, this course is usually more honoured in the breach than in the observance.

Other Attempts to Encourage Custom.—It has not been the practice to provide wiring free in this country, although one or two suggestions have been offered to show the advantages of so doing. There are now companies who make it their business to put in fixtures, and to wire either on rental or in return for a percentage upon the quantity of electrical energy supplied through their agency. Some local authorities undertake wiring themselves; others are desirous of assisting the spread of the business by granting loans to places and persons of good repute who have the wiring carried out and repay the loan by instalments. From time to time proposals are offered to wire and fit up premises on a system of hire-purchase, and motors, heating and cooking apparatus, and the like, are

being hired out to consumers by some companies and local authorities.

Free-wiring is a misnomer, and the principle generally adopted by those who undertake such work is that of a deferred payment system of purchase or simple hire as the case may be. The advantages claimed for so-called free wiring are briefly as follows:—An incentive to the consumer to take a supply of electricity, as it is asserted that the cost of wiring frequently prevents would-be consumers taking a supply; the extension of a supply into the poorer districts which it would otherwise not be possible to serve for many years; the impetus given, and the classes of lighting obtained are beneficial to the undertaking as the units sold per lamp are increased. These advantages claimed are, of course, on the assumption that the system of free wiring is accepted and the supply well taken up by the public, and that it meets a felt want. In some cases the undertakers conduct what is practically a loan system, lending the necessary money for the purpose of wiring. In the poorer districts electric lighting will not probably be taken up to a large extent until the prices are lower than they are to-day. The disadvantages of the system so far adopted are that the responsibility of an undertaking is increased as the repairs to fittings and wiring have to be provided for and any small defect remedied, the undertakers have to be responsible for defaulters and collect payments. Where the undertakers do the wiring directly there is risk of loss on the transaction unless there is sufficient work to keep a staff of men employed. The strongest objection is that money has to be invested in work which may be left in the hands of the undertakers, the intrinsic value of which represents only an infinitesimal portion of the original outlay, should

a tenant choose to leave the premises, and the greater portion of the cost entailed being for labour can never be redeemed. The London County Council have made more than one attempt to obtain Parliamentary authority for the Metropolitan local authorities who are undertakers to be empowered to provide interior wiring and fittings, and have now been successful. Several provincial municipalities have received authority in local omnibus Acts to hire motors and conduct a wiring department, the experiment usually doing well as regards motors, but with varying results in connection with wiring.

Coin-in-the-slot or prepayment meters have been found very successful in tenemented districts, and are arranged to take coppers, sixpences or shillings. Their use has tended to popularize electric lighting with the humbler classes of the community. Lamps of good quality are sometimes sold by the supply companies with a view to safeguard the interests of the consumer, and some municipal stations give away lamps at the rate of, say, one 16 c.-p. lamp per fifty-six units consumed, as a kind of discount upon payment of account, so as to relieve the consumer of the expense of renewals.

The price of electrical energy to 200 volt consumers is frequently ½*d.* or 1*d.* less than to those at 100 volts. A low rate by separate meter is now sometimes charged for lamps in cellars and back premises principally used during the day, if not less than 10, 16 c.-p. lamps be installed. Lamps further back than 9 ft. from a shop window are in some instances included in this rate.

CHAPTER V

DIRECT SYSTEMS OF SUPPLY

In dealing with systems of supply we have to consider the various means by which electrical energy, generated at a central power station, can be distributed to an indefinitely large number of consuming devices located at irregular intervals throughout the area to be supplied and utilized in proper quantities to the best advantage, the capital cost of the apparatus employed being kept as small as possible. In other words, we review the various solutions that have been proposed to the problem that a quarter of a century ago was called "the sub-division of the electric light," and is now referred to as "a general supply of electrical energy for public and private purposes."

Under modern conditions the problem is complicated by the removal of the power station outside the district served, or to a relatively large distance away from the localities having the greatest demand. The use of direct systems then becomes inadmissible, and a scheme has to be considered under two heads, transmission from the power station to transforming or sub-stations, and distribution from each of these to the area surrounding it. The simple case of direct supply still holds good for each distribution area, and it can be stated in terms that

admit of no ambiguity that the transmission portion may be added at any time to an undertaking in operation without interfering in any way with the "system" of distribution. In this section the methods of supply dealt with are those which are strictly distributive in contradistinction to such others as may be added for transmissive purposes. In other phraseology we are writing in this chapter of the retailing portion of an electric power undertaking as something apart from the bulk or wholesale section.

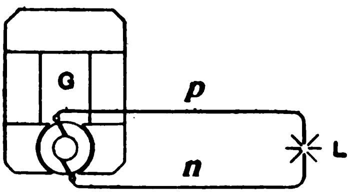


Fig. 13.

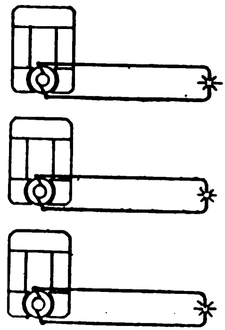


Fig. 14.

At the present advanced state of knowledge it may seem unnecessary to outline the difficulties which beset the pioneers in the industry, but in order to commence with first principles it is desirable to refer to fig. 13. This shows the most elementary form of the electric circuit, comprising a generator, positive and negative conductors, and a lamp or other consuming device. For some years after the invention of the dynamo, arc lamps were always supplied in this elementary fashion. All the direct methods of supply are merely elaborations or amplifications of this fundamental principle: they do not involve

the insertion of apparatus (other than those of a conductive character, such as switches, fuses, and measuring instruments) between the source and sink of energy, the generative and dissipative ends of the circuit. The expressive term "monophotal lighting" was applied to the method of independent supply shown in fig. 14. Small generators being relatively inefficient and expensive, and the cost of cables a serious item, inventors set themselves to find a system whereby a number of consuming devices could be supplied from one centre, each being more or

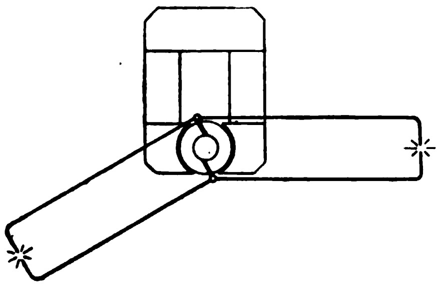


Fig. 15.

less independent of all the others, and able to receive all the power it required.

So long as the apparatus operated by electric power was of low resistance, and therefore took a large current, it was almost impossible to supply a number of devices, as the pressure-drop along the conductors interfered with the supply to the devices at the remote end of the circuit. By providing each of these with a circuit to itself, running conductors from a common generator in the manner indicated by fig. 15, practically a monophotal system with a common generator was obtained. The pressure at the generator only needs to be sufficient to supply

one lamp, allowing for drop in the conductors to it. The current in each circuit has only one value, that which suffices for the operation of the lamp, and when it is turned out no current flows. There is thus no interference with the supply to other lamps by one or more being turned out, and the pressure-drop in the leads does not introduce any difficulties.

In the simple monophotal system the supply to the consuming device could be kept at its proper value, in spite of variations in speed of the engine driving the generating machine or other causes, by maintaining either the current or the pressure constant. When more than one device was supplied from a single generator, then the two factors had different meanings; one varied with the number of devices at work, and was a measure of the power absorbed, the other remained (or steps were taken to make it) constant. The great distinction arose between mixed systems of one kind or the other, for in those intrinsically parallel in their nature the pressure was the constant quantity, while the current varied with the load; and in others, where the arrangement was primarily a series one, the current was kept to a certain number of ampères, and the pressure allowed to vary as might be necessary to fulfil this condition. Parallel systems were made a success when the resistance of each of the consuming devices was fairly high, so that the pressure lost in the conductors was merely a small fraction of the total pressure maintained between the conductors. The first great step in advance was the production of a high resistance incandescent lamp by the labours of Edison, Swan, and Stearn, resulting in the construction of lamps for a pressure of 50 to 100 volts difference between their terminals. The long-desired end then was attained,

and the distribution of electrical power only required the attention of engineers, aided by the necessary capital, to prove a commercial success.

Supply at Constant Potential enables the circuits to be consolidated so that for a part of the distance traversed the copper conductors to each are common and insulated as a whole, instead of there being separate circuits from the terminals of the generator to each lamp. Mains are run from the generator, and from these branches are taken off, as shown in fig. 16. Across the branches the consuming

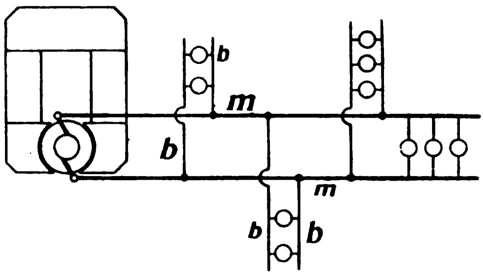


Fig. 16.

m, Mains; pressure is maintained by the generator between *m* and *m*.
b b, Branches.

devices are connected. The relationship of this diagram to fig. 15 should be noted. With separate circuits, as in the preceding diagram, the turning off or on of any lamps at one centre of consumption does not affect the others,[1] thus an excellent supply is given to each one independent of the rest, but with a common main and separate branches a fluctuation of pressure is introduced, due to the alteration in the current flowing in the mains. This departure from a constant value must be kept within

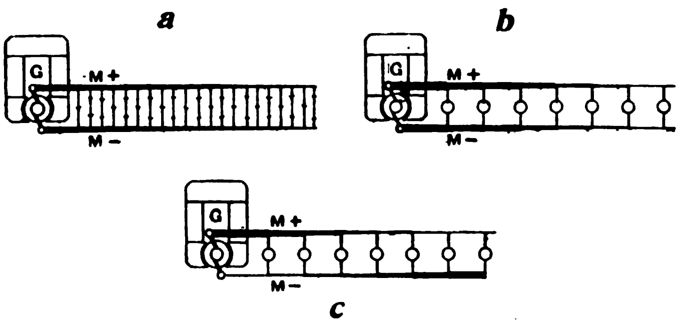
[1] This refers to the mains alone, as of course armature reaction, &c., in the generator has to be considered.

certain limits, fixed by reference to the greatest variation from the normal that can be tolerated, so that the working of the lamps or other apparatus is not unduly affected.

An obvious way to reduce this pressure drop in the main is an increase in the cross-sectional area of the main conductors. Cost usually determines the limit to which this remedy can be applied, while the pressure drop and the power wasted in the mains, which appears as heat and raises their temperature, impose an inferior limit to their size. By regulating the pressure at the generator end of the mains the average pressure can be kept at the normal, the pressure at one end being as much above as it is below this at the farthest point. The pressure drop will vary directly with the distance of the lamps from the point where a constant pressure is maintained. Absolutely constant and uniform pressure is only possible when no current is flowing in the mains, or by laying down infinitely heavy conductors. The greater the number of points at which it is possible to regulate for a constant pressure, the better the service. This leads to one method of improving the supply on a parallel system, which in different forms is largely taken advantage of in practice.

The term "simple parallel" applies so long as all the insulated metallic masses conveying current are at one or other of two pressures from earth potential (in the absence of earth leakages); the current flowing out by one conductor must then return by the other. However complicated the mains may be between the generator and the point of consumption, when this is reached, if incandescent lighting be the object, a return will be made to the simple parallel arrangement.

Conical and Tapering Conductors are used for economical reasons. As the current diminishes as each tee-joint or parallel connection is passed, it is unnecessary to maintain the same cross-section of conductor throughout the length of the mains. The number of changes in section is kept reasonably low on account of the expense of making joints, and the objection that exists to a number of made joints, inasmuch as at some future time faults may appear where they have been put in. If current is taken off equally along the conductors, they



Figs. 17 (*a*), 18 (*b*), 19 (*c*).

should have a cross-section varying uniformly from a maximum at the generator end to a minimum at the point of tapping by the last consuming device. Such an arrangement would give conical conductors (fig. 17) a parallel current flow taking place between mains with a constantly varying section. As in practice current is taken off at intervals, changes of sectional area are made where changes in current take place (fig. 18), only a few different sizes of cable being necessary.

The principle of tapered conductors is of some importance, and with conical conductors the rate of fall of

pressure—or volts drop per yard of run—is kept constant (since the current density is uniform); this is sometimes desired. An application of the conical principle is to be found in the meshes of networks where the more lightly loaded branches are of smaller section than those of more importance.

By reversing the direction of taper of one of the two conductors (fig. 19), it at first sight appears that an equal pressure would be maintained across the consuming devices. But while the total resistance of the mains to

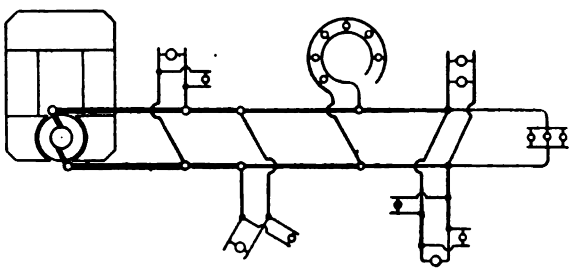


Fig. 20.

the first device is increased, and the resistance between the connections to the first and last of these is reduced (taking both conductors), this reduction occurs on one conductor in inverse proportion to the current. The total difference between the pressures across the first and last device is reduced, but that between the first and second is increased. The pressures across different devices are more unequal than before.

Tree Mains are formed by parallel circuits, joined to the cables of origin by tee-joints or equivalent means, being taken off from a pair of mains, and it will be evident that the same principle can be applied to any one of the circuits and sub-circuits supplied (fig. 20). A system of

conductors is derived which is commonly termed a "tree." The ramifications of conductors over a large area, from a central station always involve a certain amount of treeing; but the method is not a good one for general adoption and as a principle of design; firstly, there is no duplication of supply; and, secondly, as the drop of pressure increases along the mains, circuits, and sub-circuits, it usually leads to bad service on the smaller conductors. The end of each circuit and sub-circuit on a system of mains must either be "fused"—when the different sizes

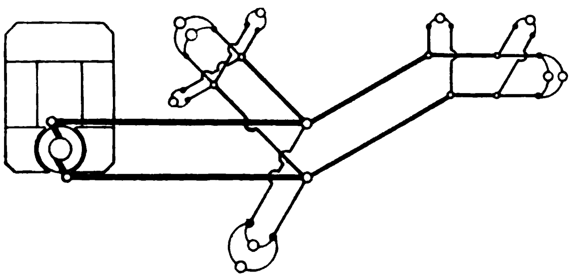


Fig. 21.

and large number of fuses become perplexing—or, if not so protected, any fault on a minor cable is liable to interfere with the supply on the whole "tree."

Distribution Centres were first proposed by a Mr. Rogers some eighteen or nineteen years ago, the idea being to connect all small circuits to the main cables by a copper ball on which were a number of terminal screws for making contact. Although it seems to have been thought that the ball would, in a way not very clearly described or apparently understood, act as a reservoir or even as a source of energy, and that some saving would accrue from its use, the proposal was a step in advance,

being one of the earliest attempts to supersede the tree system by centres of distribution. Fig. 21, showing the principle of centres of distribution, may be compared with fig. 20. Distribution-boards are very largely used in house-wiring for giving origin to sub-circuits, and in electricity supply it is now customary to provide networking, feeding, and service boxes which are suited to the conditions of underground work, and act electrically in the same way as such centres do in interior wiring. By concentrating the take-off ends of distributors and

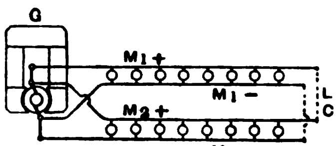


Fig. 22.

G, Generator; M_1 and M_2, Mains; L C, Looping Mains.

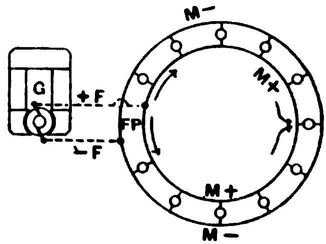


Fig. 23.

F F, Feeders; F P, Feeding Point; M M, Ring Main.

services, and by making the joints thoroughly mechanical, while they are always open to ready inspection, there is less chance of breakdown, and a more easily maintained system. In the early Edison system a number of different connection boxes were introduced.

Looped and Ring Mains are formed by conductors giving a duplicate path to every point. Starting at any point on such a main, and proceeding along it, one eventually returns to the starting place. Looped mains are imperfect rings, the near ends being connected to the generator or distribution-centre (fig. 22). The connections to a ring main both of supply and take-off are tees (fig. 23).

At various points means may be provided to cut the ring up into sections for the purpose of repairs and testing. A true ring therefore offers two channels to the inflowing current at a feeding point, and from its nature is adapted for distributing. It also gives a duplicate path for the current to any consumer, and therefore tends to improve the service, since the demand may fluctuate over the district at different times in the same evening.

Reversed Feeding was proposed by Werdermann by feeding at opposite ends—that is, one conductor is connected at its near end direct to the generator, while the other is con-

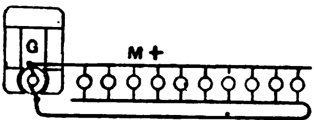


Fig. 24.

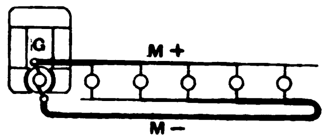


Fig. 25.

nected at its far end to a main brought back to the other terminal of the generator. The object of this is to make the resistance to any consuming device the same as that to the others, and, as can be appreciated by an inspection of fig. 24, this is attained. It was presumed that the pressure across the mains at all points would be the same. But this is only true when only one device is put on at a time; it does not matter which is used, the pressure will be the same. When more than one, or say the whole number, are connected, the pressure drop in the conductors between the first and last of the devices must be taken into account. At each end the pressure difference is higher than it is at the middle, because since the current enters at opposite ends, the pressure drop between any two devices gets less and less as one proceeds from

the supply end towards the dead end. The pressure at one end is equal to that at the other, but at each end it is higher than at the centre. Without altering the total weight of copper, it is possible to improve matters. This is done by distributing the metal in the conductors so that the current density is kept uniform. The Werdermann system combined with tapering conductors gives an almost perfectly uniform pressure, as neither end can be at a higher pressure than the centre (fig. 25).

Feeders and Mains were described in an early patent by Edison as conductors leading from the generating station to points in the area of supply where they were connected to other mains: to the latter the services or house connections were made. It is the peculiar distinction of a feeder that it is not tapped at any point except its extreme end, and at this "feeding point" the whole of the current it carries is delivered to the network of "distributing mains" (fig. 23).[1] Each feeding point is the centre of a supply area, the pressure being kept at a constant value at that point by regulation at the generator end of the feeder. Some engineers believe that in direct supply constant potential systems it would probably pay to put as much as half the capital spent in conductors into feeders. It is not too much to say that the careful designing of and making suitable allowance for the necessary feeders has done as much as anything else to improve the service given by, more particularly, low-pressure systems,[2] and it came to be seen that with

[1] Prof. Forbes, so long ago as 1889, said, "I hold the opinion that a station with low-tension current without feeders is badly engineered." —*Journ. Inst. E. E.*, vol. xviii. p. 183.

[2] See letter by Messrs. Holmes and Vaudrey on the use of feeders in Liverpool.—*Electrician*, vol. xxii. p. 634.

increasing load and longer mains high-tension stations could not successfully operate without the use of similar devices. Voltmeters in the central station showing the pressure at feeding points are either connected by conductors, termed "pressure wires" or "pilot wires," or are arranged to show the pressures at the outward ends of the cables by some special means.

The Advantage of Feeders is the ease with which the pressure can be maintained constant at fixed points in the area supplied. The pressure drop in a feeder represents a loss of power which has to be made up at the station by increasing the impressed E.M.F. at the generator end of the conductors. A liberal use of feeders reduces the difficulties inherent in all systems of distribution caused by drop, as excessive variation in the pressure at the junction of service lines with the mains cannot occur if within a hundred yards or so there is constant pressure.

Distributors are laid from the ends of the feeders throughout the streets in which a supply of electrical energy is given. Distributors are mains from all parts of which branches, or service lines, can be led into consumers' premises. A network of mains may be laid down, and current supplied to them at numerous points by means of feeders. Distributors may connect adjacent feeding points, so that current flows in at both ends, or they may be only supplied at one end, but in either case the pressure drop that takes place in the conductor cannot be compensated or regulated. It is therefore essential that the area of copper should be sufficiently great to keep the drop within reasonable limits. At intervals along the mains boxes are put in, giving access to the conductor, and at right angles service lines are taken off

These run into the premises of consumers. Distributors are usually laid of such a size that all probable future demands may be met without opening the ground or disturbing the original cables. The pressure on distributors varies along their length when full load is on. At the feeding point it is kept at a uniform value, and therefore it is less and less at points further and further removed from this position. The actual difference, however, is not allowed to exceed a small percentage, so that the lamps of the same size along a street do not differ very appreciably in candle-power.

The Two-wire System in its simple form is not sufficient for the business of a company or municipality working under a provisional order. The area that it is possible to serve from one station is so restricted that it would be difficult to cite an example at work. The two-wire system has been recommended for its simplicity where the transmission is by high pressure to sub-stations, and the area round a sub-station is dense.[1]

A generating station on the two-wire system contains dynamos (usually shunt-wound) having varying outputs, at from 100 to 135 or 140 volts, so that one or more may be used to economically meet the demand at all times. These would work in parallel on a pair of heavy bus bars, being switched in and out of circuit as the variations in load require.

A pair of distributing mains would be laid under the footways on each side of each street, and connected together to form a complete distributing network, to which would be connected all the service lines to consumers' premises. For convenience in working, the network would be divided into sections, the supply of current

[1] J. F. C. Snell, *Municipal Elect. Assoc.* 1902.

being brought to selected feeding points in the network by the heavy feeding mains which run direct from the generating stations. The different sections of mains enable the conductors to be laid at a comparatively low cost, as feeders and distributors would be laid together in one trench, the exact section put down in any one street depending upon its importance as a feeder route, and the probable demand likely to arise from premises therein.

Regulation on Low-pressure Feeders is not, as a rule, required during the first few years of working. All that is necessary can be obtained by a resistance in the field-magnet windings of the dynamos. Shunt-wound machines being commonly employed, the bus bar pressure is readily and directly controlled by varying the excitation, and as the range of variation does not exceed, say, twenty volts, this method answers admirably. Unequal loading, or, as the supply extends, the occurrence of local fogs, is unprovided for. The hours during which the heaviest current is taken vary in different streets and districts, and, therefore, not only has the bus bar pressure to be varied, but the impressed E.M.F. on each feeder or set of feeders has to be regulated. The shorter feeders may therefore be connected to a regulating switch, by altering the position of which it is possible to introduce a number of secondary cells into the circuit. These are arranged in opposition to the sense of the station pressure, so that the pressure on the feeder is reduced two volts for each cell brought into circuit. Another method is to use a resistance, but in either case the object is to cause a drop in pressure before the current enters the shorter feeders. Very long feeders may be supplied at a higher pressure than the bus bars by using a "booster," or placing cells in the feeder circuit to add volts.

The Economy of High Pressure is confined to the Mains. Since electrical power is the product of pressure into current, and the carrying capacity of a cable is only limited by the maximum current it can take without undue heating, or exceeding the greatest percentage pressure drop allowable, the power transmitted through any particular conductor may be increased by raising the pressure. The energy wasted degenerates into heat, and raises the temperature of the cable, the rise of temperature varying approximately with the square of the current, directly as the resistance of the cable and inversely with the numerical ratio of the radiating surface to the cross-sectional area.

If a particular cable will transmit 100 kilowatts one thousand yards with a drop of 33 volts at 100 volts supply pressure, it will at double this pressure, or 200 volts, transmit the same power the same distance with a drop of only 16·5 volts, as the current is halved. The percentage drop will be reduced to one-fourth, because the actual drop is half what it was before, and the pressure is twice that in the first case. The power wasted as heat in the conductor will vary as the percentage drop. A conductor of half the cross-sectional area will give the same actual or half the percentage drop, and therefore save half the power formerly wasted in mains, while reducing the capital expenditure. Or a conductor one quarter the weight of the first will give an equally good service, and only waste the same power.

This may be shown in elementary fashion, thus:—Suppose a given power, P, be transmitted a given distance, and let C represent current, E pressure, e pressure drop, R resistance of conductor. Then: $C E = P =$ power transmitted; $C R = e =$ actual drop; $C e = C^2 R = \frac{e^2}{R} =$ power wasted;

$100 \frac{e}{E}$ = percentage drop. If pressure be altered to n E and resistance of conductor to m R, then : $\frac{C}{n} \times n \, E = C \, E = P$ = power transmitted ; $\frac{C}{n} \times m \, R = C \, R \frac{m}{n} = \frac{m \, e}{n}$ = actual drop ; $\frac{C}{n} \times \frac{m \, e}{n} = \frac{C \, m \, e}{n_2}$ = power wasted ; $100 \, \frac{m \, e}{n} \times \frac{1}{n \, E} = 100 \frac{m \, e}{n^2 E}$ = percentage drop.

The saving in capital expenditure tells in many ways. A main already laid may be used for additional customers without extra expense if the pressure can be increased. Even more important is the possible reduction in the number of and closeness with which feeding points have to be set on the distributing conductors. Fewer feeding points are required, feeders and distributors may be longer, and yet a better service can be maintained at the higher pressure than at the lower one, and the cost of the mains per kilowatt may be kept at a low figure. Not only is this the case, but as sudden changes in demand create fluctuations in pressure proportional to the current, by doubling the pressure the percentage fluctuations may be diminished to one-fourth. As the pressure is increased the insulation of conductors must, on the other hand, be improved, and insulation and its protection is the most costly part of the cables. The cost of laying a light cable is not very much less than that of a much heavier one, trenching and reinstatement of footwalks being nearly constant.

The Parallel-series Arrangement combines the advantages of a higher distribution pressure without increasing the voltage across any one consuming device. The obvious way to reap the benefits of increased pressure is to run lamps and other devices two in series (fig. 26, A). The current required for a given number is then halved, and

the pressure is doubled. Arc lamps are seldom required to burn singly, and therefore on continuous-current mains they are generally run two in series, and on alternating circuits either two or three in series on 100 volts, while a series of five arcs has been run on 230 volts continuous, and nine on 450 to 500 volts, continuous. The autonomy of incandescent lighting is, however, lost, and it is no longer possible to economize energy by turning out each light individually when not required. The two devices in series must also take exactly the same current, that is, they must be specially adjusted for resistance, and this is

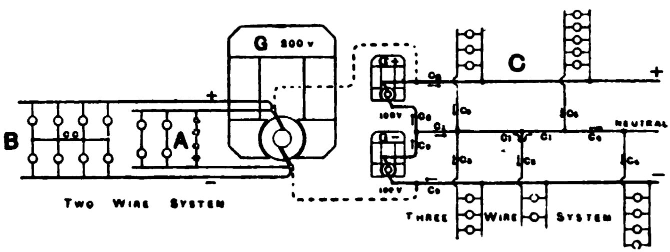


Fig. 26.

somewhat difficult to ensure. Lamps of different candle-power cannot be run together, and if one of a pair fails, the other is extinguished. An improvement on this is to arrange two or more parallels of two lamps in series with a wire joining the middle points of the parallels; then a lamp or lamps might be turned out, and yet leave the others burning. But this has a defect, inasmuch as turning out one or more lamps increases the brightness of the remaining lamps on that side, and diminishes the brightness of the lamps burning on the other side, as must be evident from fig. 26, B, where C C is the compensating conductor.

The Three-wire System eliminated this inherent defect. The late Dr. John Hopkinson [1] proposed to take the third wire back to the intermediate junction of two dynamos connected in series, so that it would become a "neutral" wire, and would be only required to take back the balance of the current from the more heavily loaded side. This was invented contemporaneously in America by Edison,[2] and also independently by another worker in England. The importance of the improvement is evident from the fact that by its use the lamps or devices are made independent, and any one or more may be put into or out of action without appreciably affecting the others.[3] (Fig. 26, c.)

The action of the third wire is somewhat complicated, and to this fact the troubles that arise in successfully managing a three-wire system are due. We have to consider such cases as the following:—

(*a*) The number of groups being the same on both sides, the number of consuming devices being the same in each group, the opposite groups being joined to the same point on the neutral conductor, which is then inoperative, and carries no current.

(*b*) The number of groups the same on both sides, the number of consuming devices the same in each group, but the opposite groups being connected to different

[1] Patent 3,576 of 1882 (amended June 22nd, 1891) for "Improvements in distributing electricity and in apparatus to be employed for the purpose."

[2] Patent 274,290 (U.S.A.) applied for Nov. 27th, 1882, and issued March 20th, 1883.

[3] For further details consult *Elect. Review*, vol. xxiii. p. 33, the High Court Case, Dr. John Hopkinson *v.* The St. James and Pall Mall Company, and W. Jenks, *Elect. Eng.*, vol. iv. p. 86, 1889; reprinted from *Elect. World*, N.Y.

points in the neutral wire. The neutral wire will then carry a varying current along different portions of its length according to the disposition of the groups.

(*c*) The total number of consuming devices the same, and the whole on one side being the same as that on the other, but the number in opposite groups different, the opposite group being joined to the same point in the neutral conductor. The third wire will then be called upon to carry varying currents proportional in each part to the difference in the number of consuming devices on the two sides, in a direction looking away from the generators.

(*d*) The number of consuming devices different in each group, and the total on one side greater than that on the other, the opposite groups being connected to the same points on the third wire. This is an aggravated case of (*c*).

(*e*) This is a combination of the foregoing. The number of consuming devices in each group and the number of groups on each side are both different, and the opposite groups are connected part to the same and part to different points of the third wire. Here we may have no current along one section of the neutral conductor, a large current towards the generator at another, a small current away from the generator somewhere else, and a small current into the station at the junction with the generator bus bars. This represents very closely the actual working of the system as it may and sometimes does occur in practice.

The three-wire system presents several points of special interest which may be summarized as follows:—

(*f*) A compensation at the source of energy for the difference between the total power on one side and that on the other.

(*g*) A local compensation between the different groups of lamps on the same mains or in adjoining buildings.

(*h*) The retention of the old parallel arrangement by which the individual control of lamps is secured, coupled with a reduction in the expense of conductors to from one-half to three-eighths of the previous amount.

(*i*) A better service (with capable management) than would otherwise be possible on a large two-wire system with a reasonable expenditure of copper.

The three-wire system with its advantages in economy of copper, and therefore in capital expenditure, the increased radius served from one station, and the reduction in pressure variations on consumer's terminals has at the same time disadvantages in the difficulty of properly balancing consumers, switchboard complications, greater tendency to faults and electrolytic troubles, and more attention required to diagnose and locate faults on the middle wire.

We have seen that the three-wire system proper includes two generators run in series, one across each side of the circuit, the neutral wire being common to both. To carry this out in practice and permit any one of the machines to be used on either side necessitates an arrangement for transposing them. The first one is to provide each generator with a double-pole two-way switch, one set of contacts throwing it on to the + and the other to the – side. We should then have a number of machines run parallel in two groups, the two groups being in series. Each pair of feeders with its neutral wire would be brought to the three omnibus bars in the station.

It has already been shown, however, that there is a local neutralizing action on the third wire. That is, it

comes into play to connect different consumers' premises in series, and different parts of the district in series. But although in any one part of the district there may be an overload, say on the + side, at another part the same thing may be taking place on the − side; yet at the station there would be no sign of want of balance on the ammeters. The pilot voltmeters might show a drop, which would be compensated for by raising the station

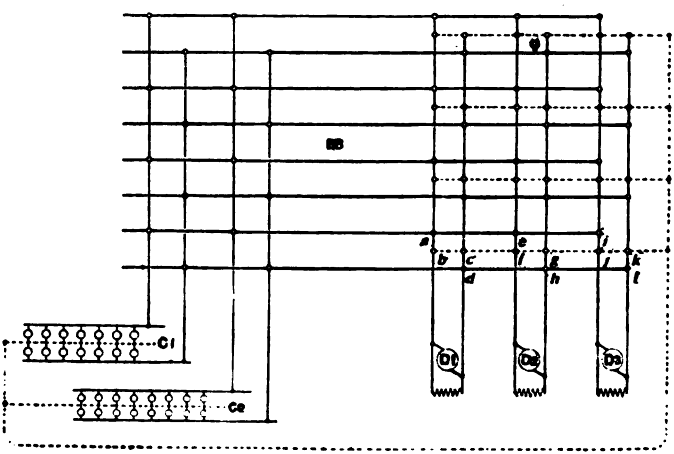


Fig. 27.

pressure on both sides slightly, or they might not, all depending upon the distance apart of the centres of demand and of the pressure points. While it is imperative to put in a neutral wire throughout the area in which distributors are laid, it is evidently not of so much importance to make a connection with the third wire a part and parcel of each feeder.

The third wire feeder, therefore, may be discarded, and only one balancing conductor brought back to the

generating station from a convenient point in the area of supply. Fig. 27 shows diagrammatically a typical set-out of conductors. We have supposed that three generators —D_1, D_2, and D_3—form the station plant. Two circuits, C_1 and C_2, are indicated, B B being the station bus bars. The station switchboard is divided into two parts—that to he right of the letters B B is the dynamo board, and to the left the circuit board. Four sets of bus bars are shown, although this number would be unnecessary until more machines were in place; but we will suppose they are provided for extensions. Machines would be added on the right, and circuits on the left. Long plugs would enable any vertical machine-bar to be connected to any horizontal bus bar, and it will be seen that whereas the dynamo board has provision for the third wire, the circuit board has not. Taking the bottom bus bars, D_1 might be plugged on at *b* and *d*, so that (assuming the top brush to be the + terminal of the machine) it would run on the negative side. If D_2 be now connected by inserting the switch plugs at *e* and *g*, it will run on the + side in series with D_1. The feeders of C_1 and C_2 would be plugged on the bottom bus bar in like manner. If the sides were balanced, no further coupling would be needful, but if one or other be more heavily loaded than its neighbour, D_3 could be added to make up the required power by *a* being plugged in at *i* and *k* if it be the +, or at *j* and *l* if it be the − side that wanted raising. The reverse process would be to plug *a*, *c*, and *f*, *h*, when the generators D_1 and D_2 would be on the opposite sides to what they were before. Or D_1 and D_3 might be run with D_2 to balance, and so on.

The object of providing additional bus bars is to enable certain long feeders to be fed at a higher pressure than

the shorter ones. When more machines are in place, two or three bus bars might be used, and kept at different pressures. The long feeders might be supplied at the highest pressure, the shorter heavily-loaded feeders at the medium pressure, and the shortest or least used feeders at the lowest pressure. A pair of machines would be required for each bus bar, with one or two wherever necessary to balance. Two-way snap-over switches are sometimes provided for changing feeders from one bus bar to another.

Balancing Three-wire Circuits is very necessary. When the loading is equal, no current flows down the neutral

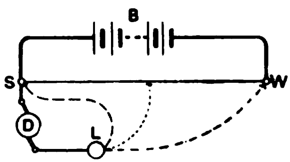


Fig. 28.

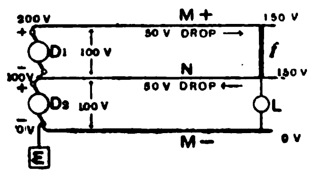


Fig. 29.

wire, and equal pressure is maintained on each side. If this could be always ensured, then the object of the system is obtained without the necessity for the intermediate or third conductor, but this has to be retained so that the autonomy of the lamps on a two-wired system may be preserved.

The effect of unequal loading is two-fold; firstly, the current taken from the + and − generators is different; and, secondly, the pressure on the lightly loaded side rises, due to the copper-drop in the third wire. The pressure on the loaded side falls, and the divergence increases as the want of balance gets greater. The conditions are the converse of those holding in the ordinary potentiometer.

Figs. 28 and 29 show the connections of a potentiometer, and of a three-wire system with a short circuit on one side (the most pronounced case of overloading). In fig. 28 let B represent a battery of the same pressure as the dynamo D, L a lamp, and S W a slide wire. If the conductor from L be brought to S, the pressure on the lamp will be equal to that given by D (neglecting the small conductor losses). As the slider is moved towards W, the pressure on L will fall, as a counter-pressure is being introduced into the circuit; when S is reached, there will be no pressure on L because (pressures) D $-$ B $=$ O, and no current will flow in S W from D, although the current will be unaltered in S W from B; B and D are in opposition.

In fig. 29 the short circuit at *f* overloads the + circuit. The current flowing to the lamp L is sent out at, say, 200 volts by the two dynamos in series. Assuming that the section of the three cables is the same, and that the full pressure of 100 volts is kept up on the terminals of each dynamo, and that the drop due to the small current, taken by one lamp, in the circuit is negligible. A drop of 50 volts will take place in the outgoing + cable, and 150 volts will be the pressure across the lamp instead of 100, as it ought to be. Unless the resistance of the neutral wire be infinitely small, this effect will always be produced, and to correct for it, it is imperative that regulating devices be employed.

There are instances where it is desired that a single generator should supply a three-wire system. If the two outside wires are connected to the brushes of a dynamo giving, say, 200 volts, and the neutral wire is taken to a third brush making contact with the commutator between the other two, a single machine might supply both circuits

without further complication. The reaction of the armature and interaction of the two unequal currents in its windings prevent this being successfully carried out practically.

An ingenious modification has been devised by M. Müller. In the case of a four-pole generator, the poles are arranged as shown in fig. 30; N_1 and S_1 being excited in series, and N_2 and S_2 in like manner. Although there are four actual poles, they really form only two. Each exciting circuit can be regulated independently of the other, and by this means the pressure on either side of

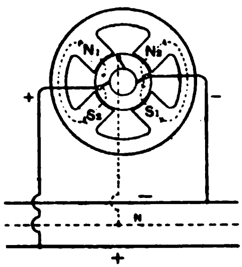


Fig. 30.

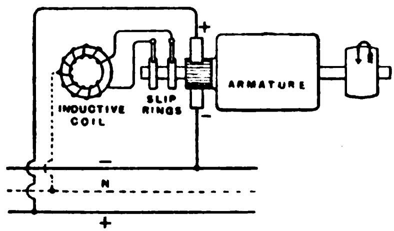


Fig. 31.

the three-wire system can be adjusted. Owing to the magnetic circuits taking the form indicated, commutation at the neutral brush can be made without sparking.

Another method proposed by M. Dobrowolski and employed by the Fives-Lille company was to interpose a coil of high inductance but low resistance in the circuit. This was connected permanently to two diametrically opposite points on the armature, or to collectors joined to such points. (Fig. 31.) The flow of an alternating current in the cross connection is checked by the high inductance.

A single dynamo with two windings on the armature

and two commutators and fields connected across the outside terminals may be combined with auxiliary batteries as shown in fig. 32: switches *a* and *b* permit the generator to be connected to the batteries or coupled directly across

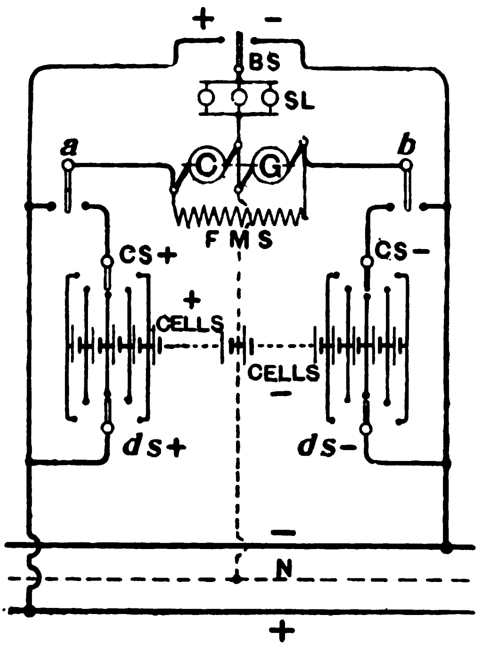


Fig. 32.

C G Compensating generator; S L Station Lamps; F M S Field Magnets; B S Balancing Switch.

the outers. The discharging switches *d s* + and *d s* — change the number of active cells in each battery. Some assistance to balancing is got by the switch B S, which places the station lamps S L on the lightest loaded side of the system.

The action which takes place in any of these balancers

is as follows :—A current of C ampères flowing back along the neutral wire is split up into current of $c +$ and $c -$ ampères at the balancing device; $c +$ flows towards the + outer through the balancing device on that side, and $c -$ in like manner goes through the − device. On the heavily loaded side the split current has been boosted up (or has had work done *on* it) and is sent out to circuit; on the lightly loaded side work is done by the other split current, which flows back into and through the generator.

In other words:

Heavily loaded side.	Lightly loaded side.
Current out to circuit.	Current from circuit.
=Current from generator.	=Current into generator.
+Current from this side of balancer.	−Current from other side of balancer.

The ratio between the two components of the balancing current depends upon the efficiency of the balancing device and the proportion that the balancing current bears to the total current on the loaded side.

Battery Compensation may correct the unbalance between the two sides of a three-wire system dynamos on the outers supplying the greater part of the power. Thus in fig. 33, D is one of the dynamos, SB + the battery on the positive, and SB − that on the negative side. The batteries here play the same part as accumulators do in a system of hydraulic supply. The battery connected to the side that is most heavily loaded discharges into the circuit and thus assists the generators, while that on the other side, which is lightly loaded, receives current and is charged. The objection to this arrangement is the difficulty of keeping the two batteries in equally good condition when wide differences occur in charging and discharging, but it is occasionally used. The switches *a*

and *c* enable the rate of charging to be adjusted, and also give means of altering the pressure on the outer bus bars, while *b* is the balancing switch allowing changes to be made in the ratio of the pressures on the two sides.

Motor Compensators are similar to high-tension motor-generators or dynamotors and consist of two armature coils wound on one drum armature. Each of these coils can, as a rule, deal with from 100 to 200 ampères out of balance current at 100 to 110 volts. The two windings are

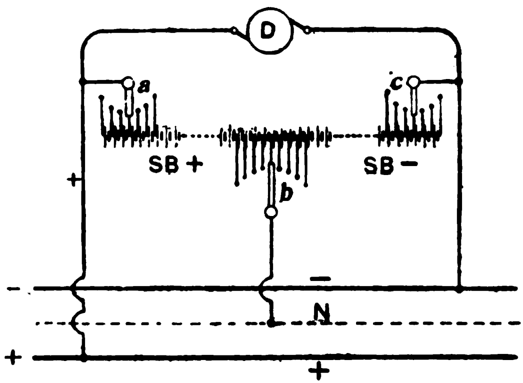


Fig. 33.

in series and connected across the outers of the three-wire system with the point where the two windings are connected together joined to the neutral wire. When one side of the circuit is heavily loaded, current passes through the armature on the other side, driving it as a motor and causing current to be sent out by the winding on the loaded side to make up for the extra load. The compensation is not perfect, because there must be a small difference of pressure on the two sides, due to the potential-drop in the machine, proportional to

the armature resistance. The following figures give the drop for various loads in a 200 ampère 110 volt compensator :—

Current through generator armature.	Difference in pressure.
9 ampères	Negligible
50 ,,	1·0
100 ,,	1·6
200 ,,	3·4

Balancing dynamotors, transformers, or motor-compensators are built either with two distinct partially compound wound machines having their armature shafts rigidly coupled together, or as one machine with two armature windings revolving between the same pair of magnets. The latter arrangement is the more common. With it the relation between the pressures generated by the two armatures is necessarily constant, and if the two armature windings consist of the same number of turns, the pressures will be equal, or different only when the windings are unequally loaded and the copper drop accounts for the loss. This may, for reasonably small loads, be discarded, but becomes of importance towards full load. The reaction of the armature current on the field magnets affects both armatures alike and does not need to be considered, sparking at the brushes being absent for the same reason. When compensators are placed in sub-stations somewhere about the middle of the distributors to which they are connected, they maintain an approximately equal pressure on the two sides without any trouble. The natural position is somewhere about the centre of the district in which there may be an out-of-balance load to be dealt with, the current being supplied, perhaps, from a station some thousands of yards away by feeders on the outer conductors. The compensators then supply current to one or other of

the two sides of the three-wire system, taking up the load as it may vary from time to time.

If the motor-generator be placed in the generating station, then the conditions are somewhat different. Should connections from the distributors be brought in to the station, the action is precisely the same as that of a sub-station. But there is the case where only a branch from the neutral wire is carried to the station and the connections to the outers have to be made to the feeder bus bars. An example of this is a station in which the dynamos are constructed to feed into the outers, and all the balancing and supply to the neutral wire is done by the compensator, aided, perhaps, by a battery. In this case the resistance of the feeders causes a difficulty in working, but the argument applies equally well to stations in which all the feeders are three-wire. In order that the pressure may be normal on each circuit at the feeding point, when the load is unequal on the two sides, it is necessary to keep the pressure on the loaded side above the normal and on the more lightly loaded side below the normal at the station end of the feeder. Suppose the resistance of the feeders be such that every hundred ampères on either of the outside wires means a loss of a volt and the same current through the balancing wire a loss of three volts. Then with, say, 400 ampères on one side and 300 on the other, in order to maintain 105 volts on each circuit at the feeding point, 112 volts must be put on the heavy and 105 on the light side, or 7 volts difference. That is, 4 volts loss in the + feeder, 105 volts drop in each circuit, 3 volts loss in the neutral and 3 volts loss in the — feeder (but the two latter are in the opposite sense, considering only the — circuit, and therefore the 3 volts has only to be counted once). The 3

volts at which the feeding point end of the neutral wire is above the station end is the same difference as exists between the feeding and other end of the − feeder, so that 105 volts only has to be maintained across the − circuit at the station. At another time 109·5 volts across the one and 106 volts across the other circuit might be required to keep the 105 volts on the distributors. If the compensator be connected directly across the feeders

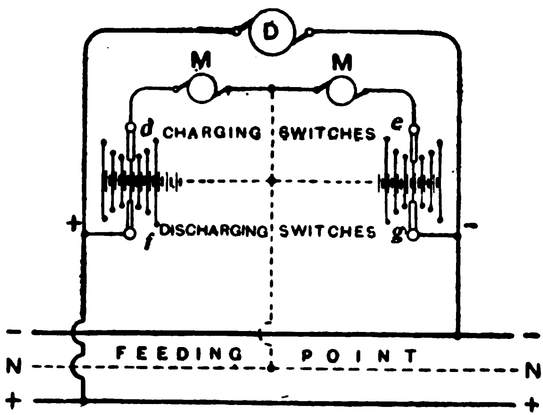


Fig. 34.

at the works, it would tend to transfer energy to the side with the least load, the converse of which should take place. To correct for this such an arrangement as now described may be used. The compensator is joined up in parallel with a second battery, regulating switches being placed between the compensator and battery, and between the leads from the cables from each end of the dynamo or dynamos and the respective bus bars or feeders. The middle points of the battery and of the compensator are connected together and taken to the neutral wire. Then

by bringing either of the compensator battery switch levers towards the centre of the cells, and the corresponding discharge or feeder lever outwards in the direction of the end of the battery, a certain number of volts is added to the pressure on that side of the circuit and *vice versa* (fig. 34). The current through the

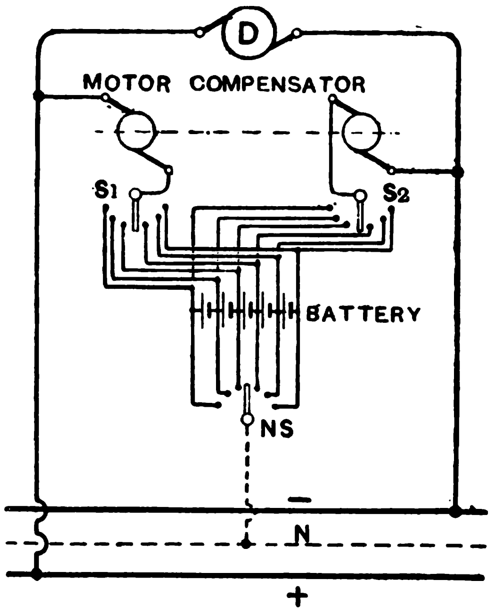


Fig. 35.

regulating battery need never exceed half the balancing current. The compensator supplies most of the power, and it also is useful in charging to bring the two halves of the battery up to the same pressure. It is therefore superior to the battery alone as shown in fig. 33, but by either device each circuit can be adjusted independently of the other with only one dynamo running.

Another arrangement is shown in fig. 35, combining a single battery and motor-compensator. This also enables the respective pressures and their ratio to be adjusted and the cells to be charged or discharged at will. A smaller battery is required than in the other methods.

Three-wire Systems in practice are now usually worked at 200 to 250 volts on each side. Continuous-current three-wire systems were first worked with a pressure of 100 or 110 volts on either side, giving 200 to 220 volts across the outers.

The increase in pressure has led to an extended use of large motors, and although, perhaps, interfering with small ones, it is convenient for street lighting, and as municipalities are gradually taking over tramway systems, the adoption of generators giving 500 volts enables central stations to supply current during the day for traction purposes, and at night for lighting. Separate mains are necessary, and it is not advisable to run both systems together from the same plant, but as the generators can be utilized for either purpose, and the steam-raising plant can be common, while the station staff can superintend the generation without any large increase in expenditure for salaries and wages, the joint operation is likely to lead to marked economies. The only objections urged against the higher pressure are:—

(*a*) An alleged decrease in light-giving efficiency of 200-volt compared with 100-volt lamps.

(*b*) The severe shock obtained from 200 volts, longer arc at switch contacts, and increased leakage, &c.

(*c*) The difficulty of running one or two open-type arc lamps economically, or supplying low candle-power incandescents.

In answer to these statements it may be said there is little evidence to show that the consumer's bill for energy

has been increased by doubling the pressure—indeed, the better effect obtained from the longer filament is appreciated by the public.

Whereas the three-wire 100-volt system was formerly carried up to the distributing board in consumers' premises where the demand was heavy, with the increased pressure this is not permissible,[1] and supply is given at a pair of terminals on the two-wire system.

The Five-wire System is a development of the three-wire system, and consists of two heavy outer and three intermediate conductors.[2] The pressure between the outers being, say, 400 volts, lamps of 100 volts are connected, four in series, with their intermediate junctions joined to the respective inner conductors, while other consuming devices and higher pressure lamps may be placed across the centre and one of the outer wires, making a three-wire system, and still larger devices, such as motors, between the outers directly. Very great facility is given for supply at different pressures, the limit being defined by compliance with the regulation fixing the maximum that is regarded as "low pressure." Otherwise there is no reason why seven and even nine-wire systems should not be designed; but although the higher pressures would enable the cost of mains to be reduced, the multiplicity of wires would lead to increase in the difficulties of working, and the need of careful balancing between the different circuits would make it increasingly troublesome to keep a fixed pressure throughout.

[1] According to the Board of Trade Regulations, the pressure between any pair of terminals at which supply is given must not exceed 250 volts.

[2] "The Application of Siemens' Five-lead System."—*Elect. Review*, vol. xxv. p. 509.

Five-wire systems are not likely to be perpetuated, but it may still be desirable in certain localities to lay intermediate conductors between the neutral and each outer should there prove to be a demand for supply at 100-110 volts, compensation being arranged for by balancing motor-generators at some convenient point.

Earthing the Middle Wire or neutral conductor of a three-wire system became a matter of importance when the feeding pressure was raised to 500 volts. So long as the outers had not more than 250 volts between them, the pressure to earth of any of the mains could not be greater than this, and in working the natural condition was such that the energy wasted by leakage was a minimum.[1] With the increased pressure some precaution was required to prevent either of the outers rising to a higher pressure than 250 volts from earth,[2] as would occur if a fault came on one of the outers, resulting in the liability of consumers receiving a dangerous shock and increased fire risks.[3] It was accordingly decided by the Board of Trade that the neutral wire should be connected at earth at one point, the difference of pressure being confined to 250 volts on either outer, respectively positive and negative to earth.

The proposal to utilize an uninsulated neutral conductor throughout has not been considered satisfactory, firstly owing to the electrolytic troubles which would follow the passage of a current through the earth, and, secondly, the

[1] C. H. Wordingham "On the Maintenance of Certain Portions of Distributing Systems at Earth Potential."—*Mun. Elect. Assocn.*, 1900.

[2] Board of Trade Regulations. See Appendix.

[3] Alex. Russell, "The Regulation of the Potentials to Earth of Direct-current Mains."—*Inst. Elect. Engrs.*, vol. xxx. p. 326, 1901.

FAULT TEST-PANEL.

−

NEUTRAL

+

NORMAL POSITION OF SWITCHES.

A. OPEN.
B. SHUT.
C. OPEN
D. OPEN.

If a + or − Cable fault comes on, the fuse F_4 blows and the lamp L. lights.

The faults to be tested for DAILY are :-

(1) Faults on Positive Feeders or Distributors.
(2) Faults on Negative " " " ".
(3) Faults on Neutral " " " ".

(ALL SWITCHES OPEN.)

(1) POSITIVE FAULTS.

If there is a + fault, on closing either B or C, the fuse F_4 will blow and light lamp L: if this occurs shut D, thereby short-circuiting lamp and Ammeter A_2. The reading of the fault will then be shown on A_1.

(2) NEGATIVE FAULTS.

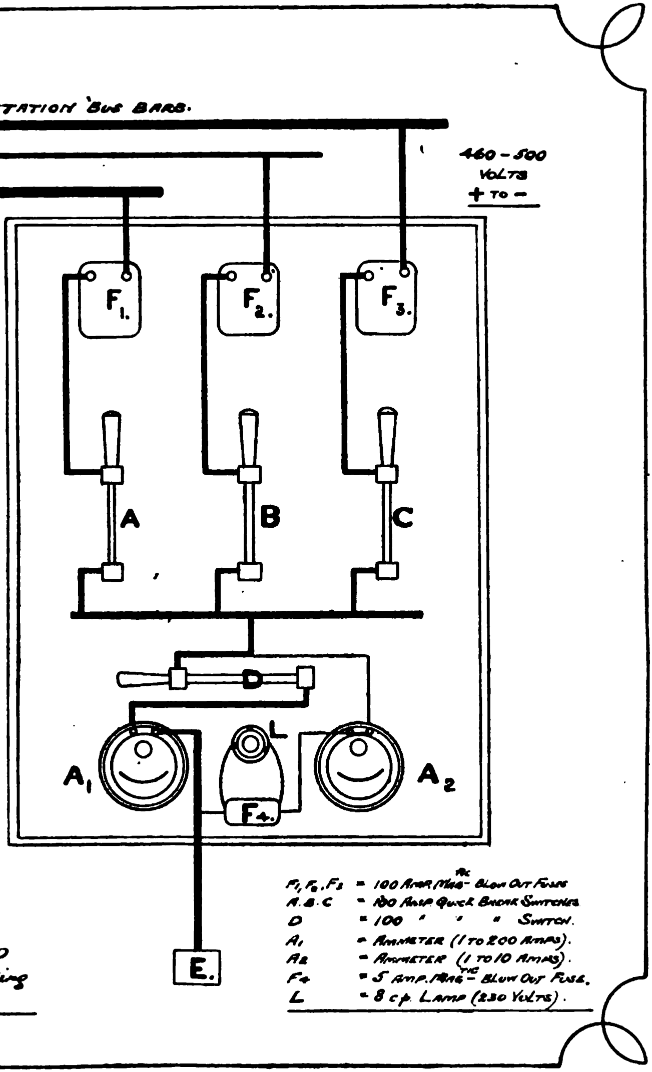
If there is a − fault, on closing either A or B the fuse F_4 will blow and light lamp L: if this occurs shut D, thereby short-circuiting lamp and Ammeter A_2. The reading of the fault will then be shown on A_1.

NOTE. In testing for + or − faults, the reading of the Ammeter A_1, will be different according as B or C, A or B respectively, is closed; for the Volts in one case = 230 & in the other = 460.

(3) NEUTRAL FAULTS.

If there is a neutral fault, on closing either A or C, th[e] fuse F_4 will blow and light lamp L: if this occurs shu[t D,] thereby short circuiting lamp and Ammeter A_2. The re[ading] of the fault will then be shown on A_1.

Fig. 36.—Three W



e Fault Test Panel.

[To face p. 133.

impossibility of making tests of insulation of the system as a whole.

The earth connection is generally made on the neutral bus bar at the generating station, means being provided for isolating the bar for testing purposes. One form of testing panel is shown in fig. 36, the testing operations being fully described by the instructions accompanying it.

On large systems it has been found that it is advisable to insert a resistance of about 20 ohms. in the earth connection to limit the rush of current in the event of a fault. By introducing a variable resistance in the neutral bar it is possible to ascertain the insulation resistance of each of the three conductors.[1] The leakage current through the earth connection of a three-wire system is continuously recorded by a low-reading ammeter. On high-pressure systems the outer conductor of a concentric system of feeders is earthed permanently at the station. In this case, as the outer conductor has a higher capacity than the inner, it naturally takes the earth pressure, and the connection merely ensures the stability of this condition: should a fault cause accidental connection to be made by the inner with earth, the rush of current then blows the circuit fuse and cuts out the faulty main.

Supply with Constant Current is the alternative to supply at constant pressure. If the intermediate conductors on a three- or five-wire system are discarded, and only one group of lamps is considered, it is evident that they form a simple series circuit. With perfect balancing, these systems theoretically resolve themselves into parallel-series arrangements. The distinguishing feature of their working is that they are operated at constant potential.

[1] A. M. Taylor, "Network Tests and Station Earthing."—*Inst. Elect. Engrs.*, February, 1903.

From 1880 to the end of the decade, steady progress was made in working out the details of constant current systems.[1] Series connection is now to be met with in special cases only, as the series-parallel arrangement has been displaced for general supply by constant potential methods. As the maximum pressure is limited to 2,000 or 3,000 volts, a large current must be maintained to give a reasonable power on each circuit. The objections to series working for general supply are—(*a*) the danger that is introduced by the large differences of pressure between the terminals of consuming devices at considerable distances apart on the circuit, (*b*) the necessity of keeping the circuit always closed, (*c*) the difficulty of regulating the power given to different consuming devices as they are dependent on one another, (*d*) with a large demand, high pressures are soon reached, limiting the number of devices in circuit, and (*e*) the only way to extend is to run additional circuits and supply these from additional machines. These circuits take up a great length of cable, and are costly to erect and maintain, owing to the numerous lengthy and small cables required.

On the other hand, a series system appears at first sight to be desirable, because (*a*) lamps of small candle-power, with short filaments, can best be made to work at a low pressure, while it is an easy thing to raise the pressure on a circuit up to 2,000 or 3,000 volts, the limit being set by (1) the insulation of the armature and coils on the generator, (2) the possibility of commutating the high-pressure current, and (3) the condition of the cables and mains, and of the apparatus supplied. While pressure drop is not a trouble, the fact that the full current is

[1] "On the Distribution of Electric Energy by means of Constant Current." Alex. Bernstein, *Electrician*, p. 14 *et seq*. Nov. 29th, 1889.

always flowing through the conductors means that a constant loss of power is taking place, and this is a high percentage at small loads. As this can only be reduced by spending more money on cables, then one of the advantages of series working is lost.

Series Arc Circuits were used before the incandescent lamp was sufficiently reliable to be employed outside the laboratory. As the arc lamp consists of regulating mechanism by which the carbons are kept at a fixed distance apart, the arc can best be kept at a uniform state by regulating for constant current through it, and permitting the mechanism to adjust the pressure across the lamp. On the other hand, if an attempt be made to run arc lamps at constant pressure, any variation in the consumption of carbon or length of arc—whether dependent upon the action of the mechanism or independent of its control—is extremely likely to cause rapid and large fluctuations in the current, and therefore lead to unsteady light. Put very briefly, therefore, arcs are most advantageously run on circuits operated with constant current, and where circumstances render it desirable or necessary to supply such lamps from constant-pressure circuits, means have to be employed to check and limit the tendency that then exists to create variations of considerable magnitude in the current taken from the mains. Series arc circuits have therefore survived as the principal example of constant-current supply. In this country they are confined almost wholly to public or street lighting, as climatic conditions and the difficulty of maintaining good insulation in a comparatively humid atmosphere would involve risk to the consumer, and would imperil the general safety were large differences of pressure possible between the fittings or conductors and earth in business premises and other frequented places, as

might result from a leak on a series circuit. Power circuits have been run on a series system in districts on the Continent.[1]

Series Incandescent Circuits were tried owing to the success that had attended the use of arc lamps run in series. Twenty-two or twenty-four years ago the consumers were scattered, and comparatively few in number; the supply was used for lighting only, and during the day the plant was shut down with the object of minimizing expenses. All these considerations were in favour of series working, with the decrease in number of joints on the circuits, overhead wires, the existence of satisfactory constant-current dynamos, and incandescent lamps of low pressure with short thick filaments. Thus we find that attention was early devoted to overcome the one difficulty, the replacement of a lamp which might fail by fracture of the bulb or broken filament, which would open the series circuit, and required some means, or *cut-in*, to short-circuit the defective device or introduce another to replace it.

Amongst the different series and series-parallel arrangements falling within the category are the Brush, Thomson-Houston, Westinghouse, Edison-Municipal, Heisler, and others emanating from the United States, the Bernstein,[2] and Goldston,[3] Kennedy,[4] the systems at Brighton and Hastings, and more recently the Parfitt in this country. Although for the most part of historical interest, there lies latent a tendency to revive or re-discover methods of achieving the same result.

[1] E.g. Geneva and Genoa.

[2] "Electric Lighting by Low-resistance Glow Lamps."—*Journ. Soc. Tel. Eng.* vol. xv. March 25th, 1886.

[3] *Elect. Eng.* vol. iv. p. 129, Aug. 1889.

[4] "Electrical Distribution by Alternating Currents and Transformers." —Rankin Kennedy, 1887, p. 53.

CHAPTER VI

CONVERTED SYSTEMS OF SUPPLY

Converted Supply.—Where the conditions of the supply are such that the pressure may at any time exceed 500 volts, if continuous, or 250 volts if alternating, the supply is deemed under the Board of Trade regulations to be a "high-pressure" supply. This is not very definite, but it is held by some authorities that there is nothing in the regulations to prevent a low-pressure direct system being supplied at 1,000 volts at the station end of the feeders so long as the pressure at the feeding points does not exceed 500 volts between the outers of the three-wire system. This is based on the assumption that the feeders are entirely under the control of the undertakers, and that nothing that may happen thereon can directly affect the consumer. Taking this view, when the pressure at which current is delivered to feeding points would exceed 500 volts on a system of parallel distribution, some means have to be taken to convert or transform it down to the pressure required by the lamps and other consuming devices. If in designing a system of general supply for a large area economy in capital outlay on distributing plant, continuity of supply, ability to reach any part of the area and to efficiently cover the whole of the district, are conditions not fulfilled by the three-wire system on account of the amount of copper required and

consequent cost of conductors, the only alternative is to have resource to some method whereby a higher pressure than 500 volts can be used on the principal system of mains and the economy of high pressure attained. The mains will then have to be highly insulated, so that the cost of a given size of cable will be greater than for low pressure. Consumers cannot, however, be directly connected to high-pressure conductors, because the Board of Trade will not permit it, and also owing to the apparatus in which electrical energy is to be used requiring a low pressure. The intermediate stepping down must therefore be effected by some suitable device. Of these there are many forms, differing in character as they are chemical, rotary or magnetic, and depending upon whether they are to be used with continuous or with alternating currents.

The insertion of additional apparatus in the circuit between generators and consumer must militate somewhat against the adoption of high pressure, since these appliances add to the initial cost, cause a loss of energy in performing their normal functions, and figure in the bill for maintenance. As a matter of fact, however, high-pressure systems are nowadays only used to give origin to a number of low-pressure systems, or, in other words, the function of the high-pressure mains is to act as feeders. The choice may be fairly said to lie between direct low-pressure supply with several generating stations, and a converted high-pressure system with several low-pressure distributing or sub-stations. We have now to consider the different methods in which the latter conception may be carried out in practice.

The Secondary Battery was one of the first means brought into use for the conversion of high into low pressure currents. If a number of cells are charged and

discharged, the one process following the other at varying intervals, depending on the demand for electrical energy and the rate at which power is taken, there is a flux of energy from the charging to the discharging side. If the same grouping of cells is kept in both operations, the ratio of transformation will be a little less than unity, owing to the difference between the charging and discharging terminal pressures. This can, however, be got over by simple regulating switches and auxiliary or back E.M.F. cells. If, instead of keeping the same connections, the cells are charged at a suitable higher pressure in groups connected in series, and discharged with the groups joined in parallel, so as to give a lower pressure, although the flux of energy will be approximately the same, the ratio of transformation will vary as the number of groups into which the battery is divided. At first sight this proposal appears very promising, but the space taken up by the batteries, the comparatively low all-round efficiency, and large expenditure for upkeep and maintenance have shown that in practice the disadvantages outweigh the advantages.

In the case of low-tension systems, the outlying battery sub-station has been and still is being applied, the idea being to charge the sub-station batteries, during the day or hours of light demand, through the ordinary feeder system, which is at that time practically lying idle.[1] At night each sub-station acts as the centre of its own area, and the batteries discharge through the distributing mains, thus maintaining the pressure at distant points; aiding the generating plant in the energy output by making it possible to meet a very much higher maximum

[1] For an extended discussion of this point see Addenbrooke, *Journ. Inst. Elect. Eng.* vol. xxv. p. 214, 1896.

load with a given capacity of plant installed than would otherwise be the case; and improving the load-curve on the plant during the hours it is running, thereby raising the efficiency. Examples of the battery transformer system are the Consolidated Electric Company's experimental lighting at Colchester, 1884 to 1886, the Chelsea Company in 1889, and the Cadogan Company. Particulars of these appeared in the first edition of this work.

The High-pressure Continuous System is theoretically the simplest, comprising an electric motor, the input of which is taken at high pressure, coupled to a dynamo the output of which is given at low pressure. The combination of a continuous-current motor with a dynamo of the same class forms a continuous-current transformer or motor-generator, which enables high pressure to be used on the motor side, and forms the principal device in a continuous-current transformer system, the power given out being obviously equal to the power taken in less the sum of the losses in motor and dynamo due to copper drop (C^2R), eddy currents, and magnetic and mechanical friction (hysteresis, windage, and bearing friction, &c.).

The high-tension continuous-current system of supply has been extended by the adoption of mechanical rather than chemical converters. A "continuous-current transformer" is a motor-generator, wound for high pressure (from 1,000 to 2,000 volts) on the primary, and 100 to 400 volts on the secondary. These transformers are placed in sub-stations at different parts of the district to be supplied.[1]

[1] "High-tension Continuous-current Supply," A. Wyllie, *Lightning*, p. 241, March 25th, 1897. "Some Notes on the Oxford System," J. Hardie McLean, ibid. p. 75, Jan. 27th, 1898.

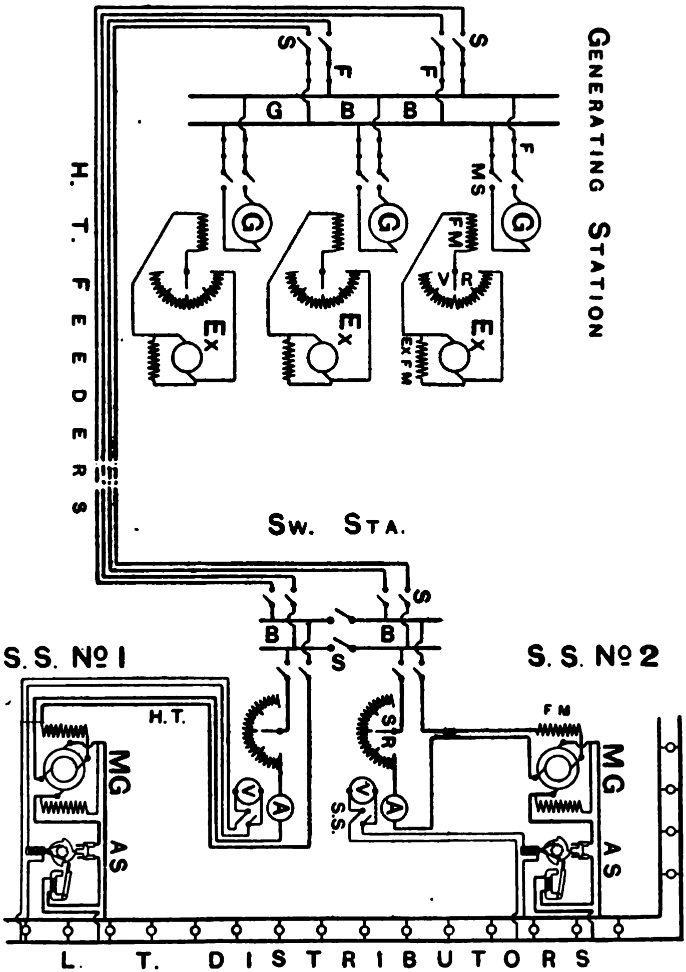


Fig. 37.

Fig. 37 gives in diagrammatic form the relationship of the parts of the system. The generating station is

connected with, say, two sub-stations, S.S. No. 1 and S.S. No. 2, by H.T. feeders, which can be controlled at the switch station, Sw. STA., where starting resistances and starting switches, S.S., are located. By closing these the automatic step-by-step switches, A S, are caused to switch on the motor-generators, M G, to the low-tension distributors. The two advantages of most importance, which have been considered in several cases sufficient to render desirable the adoption of this system, owing to peculiarities in the character of the area supplied, are:—

(*a*) The supply of continuous current; thus making it possible to run small motors of high efficiency, to deal with electrolytic processes, and charge secondary-battery vehicles.

(*b*) The use of secondary batteries, as a reserve in the generating station, or for the purpose of equalizing load and adjusting pressure at sub-stations.

Where a continuous-current low-pressure system has been originally put down, continuous-current transformers in sub-stations, with high-pressure feeders, form a convenient and satisfactory means of dealing with increased load when the demand causes the low-tension feeders to be inadequate and the distributing system to become overloaded, or should extensions to outlying districts be under contemplation.[1] The original system then remains part of a concordant whole, the high-pressure portion being added for transmission only.

Coming now to the disadvantages, it must be prefaced that whether these prove of relative importance or not depends—like so many other things in electricity supply

[1] E.g. Hull. A similar proposal was made for Aberdeen, but was discarded in favour of a second generating station.

—upon the class and duration of the load and kind of area in which energy is sold.

With continuous-current transformers, more or less weight has to be given to the following points :—

(*c*) The transformers are pieces of running machinery. Therefore they are subjected to all the troubles of wear and tear, require lubrication, &c. But are balanced, have no external forces to contend with, being self-contained, and are not troubled with sparking.

(*d*) Sub-stations must be provided to contain the motor-generators. Continuous-current transformers must be placed in positions where attendants can get round them: access to brushes, lubricators, &c., must be given, and space allowed for removal of armature, if necessary.

(*e*) Distribution can only be effected by a two-wire network, unless arrangements are made for independent balancing.

Continuous-current transformers have been mentioned so frequently that it is interesting to collect together the uses to which they may be put, and the services they render.[1]

1. Motor-dynamo, acting as transformer, converting down from high-pressure on motor to low-pressure on dynamo.

(*a*) Sub-station fixed ratio dynamotor; (*b*) meter-testing dynamotor.

2. Motor-dynamo, acting as step-up transformer, converting up from motor to dynamo.

(*a*) Generating-station feeder dynamotor; (*b*) cell-charging generator.

3. Motor-dynamo, taking power from outers of three-wire system, and supplying balancing current to more heavily loaded side.

4. Motor-dynamo, compensator, joined across outers on a three- or five-wire system, with connections to intermediate wires.

(*a*) Balancing compensator; (*b*) feeding one side when only other side is fed by generator.

5. Motor-dynamo booster, adding pressure to out-going current.

(*a*) Boosting on feeder; (*b*) boosting for charging cells.

6. Motor-generator regulator, coupled to heavy fly-wheel, for in-

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[1] See also "Rotatory Converters," S. P. Thompson, *Inst. Elect. Eng.* November 10th, 1898.

stantaneous storage in cases where traction or other rapidly-varying power is supplied from lighting system.

The High-pressure Alternating System is practically the readiest way of changing the pressure factor of electrical power, using an alternating current, and a magnetic transformer, the principle of which is interlinking the primary and secondary windings by an iron core through which the magnetic flux, induced by the primary coil, passes. The ease with which transformers could be put into service, when once manufacturers commenced their manufacture, led to an extended use, but it was many years before the highly technical details regarding their construction and combination had received sufficient attention to enable them to work efficiently, satisfactorily, and reliably. The investigations of Cardew, Kapp, Swinburne, Fleming, Mordey, Kennedy, Ferranti, and many others in the laboratory and the workshop in this country, on the Continent, and in the United States, have made the alternate-current converter to-day a thoroughly efficient and reliable piece of apparatus.

House Transformers were employed in the pioneer systems of alternating supply; several independent alternators being each driven by its own engine, the distribution being usually effected by a number of overhead high-pressure mains, from which branches were taken off to feed small transformers fixed on consumers' premises, resulting in a heavy outlay on transformers and a comparatively low efficiency. This system sufficed for country towns and straggling villages, but it was really little more than a number of independent plants grouped together in one building. Breakdowns were provided against by change-over switches, so that any generator could be connected to any circuit.

The great objection to the house-transformer method is the low all-day efficiency of the transformers themselves. A large number of these devices have to be employed, and they are at all times connected to the mains, each constantly absorbing the power required for magnetization. Danger also attaches to the use of long lengths of high-pressure mains with numerous joints and branches which enter private premises, where the risk of fire and accident is considerable owing to the impossibility of maintaining proper control over the various apparatus.

Pole Transformers were used in the earliest attempts to combine the advantages of high-pressure generation with low-pressure distribution in the United States. The early practice of the Westinghouse Company was to run overhead cables for both high-pressure and low-pressure conductors on pole lines with transformers inserted between the two pairs of mains at intervals. This method of carrying out the work was in principle what is now being done in many English towns with street transformers, and theoretically there is no difference between high and low pressure mains run parallel to the frontage of a street on a pole line, with a transformer between the mains on each pole to act as a feeding-point, and a similar disposition of conductors underground with street transformers at the corner of each of the more important cross streets.

Street Transformers, in tanks or boxes under the public footway, have been largely used where the demand in a district is scattered and there are objections to bringing high-pressure services into private premises. When it was proposed to use this system in the metropolis, the London County Council opposed the scheme on the ground that the undertakers possessed no authority, under

their respective Orders, to use the footway or carriage-way for this purpose, and, in order to decide the matter, the Board of Trade convened a meeting at their offices in December, 1894. The Metropolitan undertakers contended that they were empowered to use street-box transformers under section 12 of the County of London (North) Prov. Order, 1892, but the Council held that when the Order was drafted nothing of the kind was contemplated, and it was, therefore, unduly straining the true intent and meaning of the section to interpret it in that manner. Fortunately, the Board of Trade ultimately ruled that the Order covered the use of transformers as suggested by the undertakers. Mr. Swinburne and Mr. Dawbarn were among the first to suggest the placing of transformers in separate underground pits. The advantages of laying a pair of low-tension distributors parallel with high-tension mains and transformers, connected on one side to the high-tension mains and on the other to the low-tension distributing system, are obvious, as not only are the low-tension conductors kept comparatively small, but the pressure can be maintained at different points by simply inserting additional transformers when and where necessary. This procedure is best adapted for situations where the load is patchy—for example, where the character of the premises repeatedly changes at short intervals, and it is unlikely that consumers will be found for a few hundred yards at a time, the frontage being broken up into sections where the consumption is heavy for a short distance, and then unproductive. Another case is where the mains run into residential districts, and the best position of transforming points is uncertain, although it is known that the demand cannot be very heavy. In these cases the ease with which a transformer pit can be

put in at any convenient point that eventually proves to be suitable, is manifestly in favour of this method as against others. Transformers not exceeding 50 kilowatts are best suited for this purpose—indeed, the Board of Trade usually object to larger sizes.

The best positions at which to locate pits or tanks are the junctions of main and cross streets, the distributors radiating outwards as from an ordinary feeding-point.

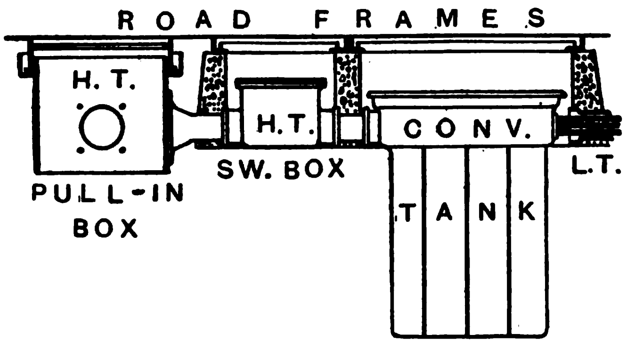


Fig. 38.

If the congested state of the subsoil prevents the best position being actually taken up, the transformer can be placed where space is most readily found, and where the disturbance to the footway by the necessary covers and frames is least likely to interfere with the user of the footwalk by the public, and feeders run to the nearest point on the distributors.

The containing tanks, of cast-iron (fig. 38), are fitted with water-tight glands or sealing chambers for the incoming and outgoing cables; the covers are in duplicate, one closing the tank by a water-tight joint made either with an oil-channel in the upper part of the tank into

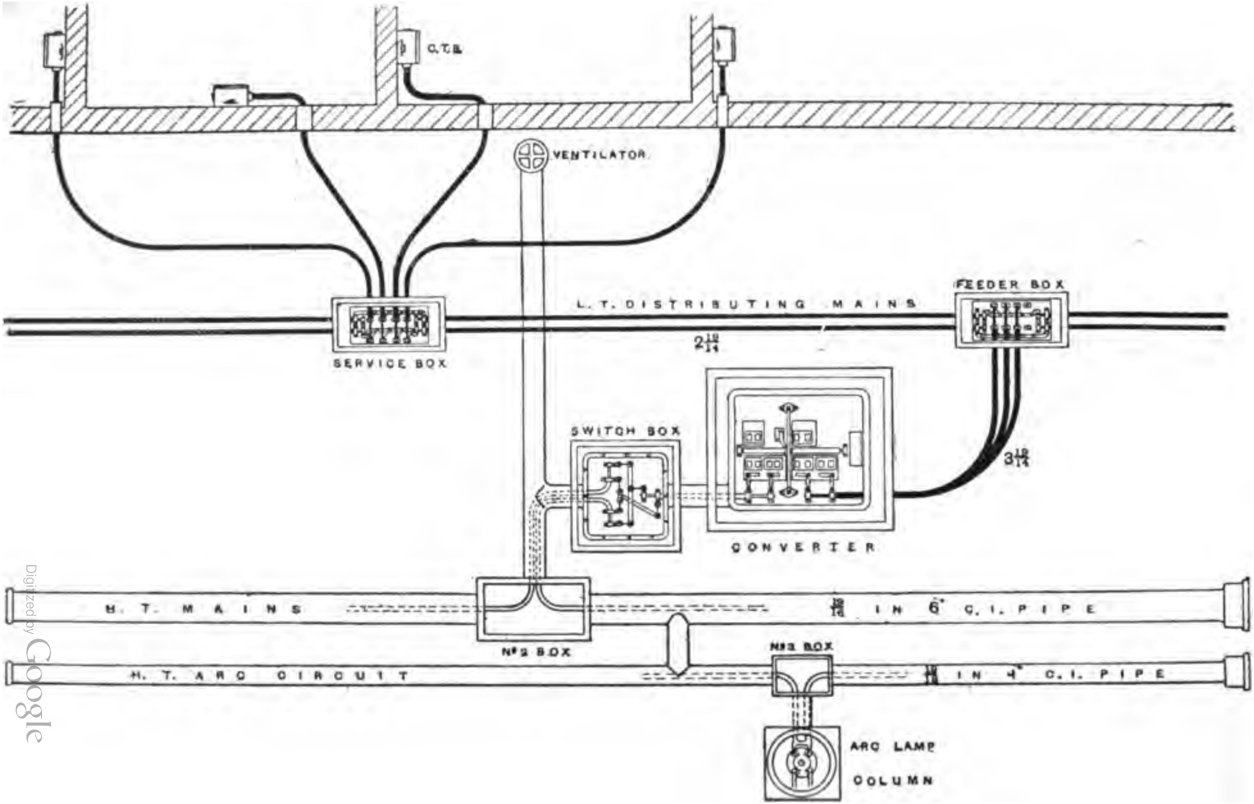


Fig. 39.—Connections of Street Transformer System.

which a lip on the cover slips, or faced joints and insertion washers or gaskets may be preferred; the outer cover consists of a frame carried by brickwork or concrete on which rests the road-cover on a level with the street surface. Strips of copper, radiating outwards, effectually earth the top cover. The heat given out by the transformer tends to keep the interior of its chamber dry, any moisture which may be present in the air or find its way in being absorbed by a tray of caustic lime, chloride of calcium, or caustic soda.

An arrangement of street transformers is illustrated in fig. 39, showing a draw-in system for arc-lighting and high-tension mains, and a buried system of two-wire distributors, with concentric cables. A cast-iron pipe line takes the cable for the continuous-current arc lamps for public lighting. Another pipe, also of cast iron, is provided for the H.T. feeders. This pipe is connected to ventilators set level with the flagging on the footwalk, and at intervals the two pipe lines are connected together. The smaller pipe is connected by tees to the lamp columns, and there is thus a system of induced ventilation, the fresh air being taken in at the ventilators, drawn through the pipes, and discharged at the top of the columns, the natural differences in temperature being sufficient to promote circulation. Parallel with the two pipe lines run the L.T. distributing cables. These are broken into sections by the insertion of feeding, tapping, and service boxes. Drawing-in boxes of various sizes are provided on the pipe lines. The high-tension feeder is taken into a switch box and led out again, the continuity of the main being maintained by plug switches in the box. The tee to the transformer is taken off by a plug on the outer conductor and a fuse on the inner, a short

piece of cable running into the transformer tank (fig. 40). From the secondary of the transformer low-tension cables run into a feeding box. The distributors run right and left, and, as required, service boxes are put in, from which consumers are supplied. All tee connections to the distributors are made by fuses on both poles. The distributors themselves are cut up into sections by disconnecting bars, which can be seen in the right-hand side in the service, and on the left in the feeding box.

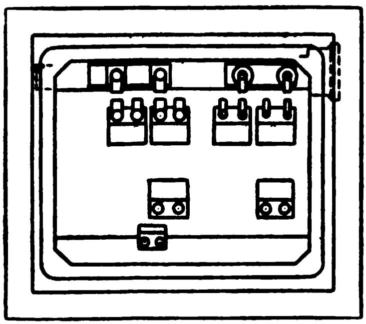


Fig. 40.—Plan of Street Tank Transformer.

The Advantages of Street Transformers are:—(*a*) No rent has to be paid for site. (*b*) Feeding points may be distributed as desired, at centres of maximum load, located as may be necessary with increasing demand, and corresponding to numerous small sub-stations. (*c*) Size may be increased by merely changing transformer if original tank be large enough. (*d*) Good pressure distribution may be secured with small and inexpensive cables for distributing. (*e*) Large and efficient transformers may be used, with a saving in installed capacity, as individual consumers' times of maximum demand are not coincident. (*f*) Avoidance of troubles from ventila-

tion or presence of gas or water. (*g*) They are rapidly put to work, and involve only a small expenditure beyond the apparatus itself.

Against the foregoing must be placed the following objections:—(*a*) The risk in opening the tanks for the purpose of changing or examining converters in wet weather or when the air is heavily charged with moisture, and the ease with which dust blows in to the tanks when these are opened in fine dry weather. (*b*) The numerous surface covers of large size that are introduced into the public footways and the consequent inconvenience occasioned to the public when these are raised for any purpose, while at least two men are required to lift the covers, owing to their weight. (*c*) The distance that has to be traversed to examine the converting apparatus, and the time and labour that is necessarily incurred in keeping so many *separate* pieces of apparatus in efficient working order. As several transformers are connected on one main it is a difficult and lengthy process to locate a fault unless a section of the supply is adversely affected. (*d*) The chance of nuisance being occasioned by the humming that is set up by the periodical reversal of magnetization of the cores of large converters. For this reason the pits should not be constructed adjacent to footings of walls of inhabited premises.

Transformer Sub-stations consist of underground or overground premises, and vary in size from those places where a large number of converters are banked together to those in which room is provided for not more than two or three. A sub-station can be developed from a small shed erected, with a consumer's consent, adjacent to his premises, with only one transformer of reasonable size, which could supply several people round about. As the demand increased this could be extended, and a sub-station proper constructed.[1]

Underground sub-stations may be placed below the footway or roadway of streets. Examples of such chambers are given in fig. 41 and figs. 42 and 43, where the

[1] *Journn. Inst. E.E.* p. 234, vol. xx.

transformers are indicated by T, the switchboards by S B and S, the entrance ladder by L, feeders and conduit pipes by F and P, surface and inner covers by S C and I C, and ventilator by V.

Large sub-stations require a room of considerable size, and as this cannot always be obtained under a public thoroughfare, premises on private property have, in such cases, to be purchased or rented. It would be out of the

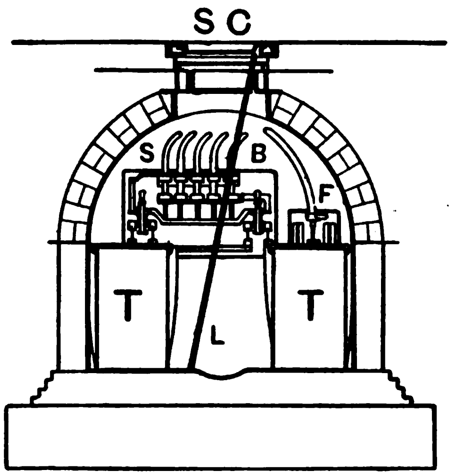


Fig. 41.

question to have numerous centres of distribution under such circumstances, as the demand is great enough only in densely populated districts to render it necessary to resort to this means of finding a proper place for the converting plant, and it is in such neighbourhoods that land and buildings are valuable and costly. Owing to the accidents which have occurred in small sub-stations, the Home Office has issued some recommendations with

regard to their design and dimensions, a summary of these is given in Appendix G. Under the Factory Act of 1901, the Home Office have a right to inspect sub-stations in the same manner as generating stations, these being classed in law as Factories.

The efficiency of distribution is usually taken as the ratio of the units delivered to the feeders compared with the units sold. Any loss due to non-registration of energy by the consumer's meters is debited against distribution, but if this be reduced to a negligible quantity by careful

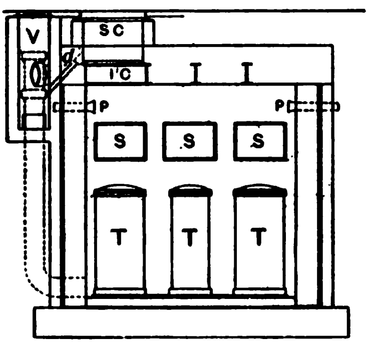


Fig. 42.

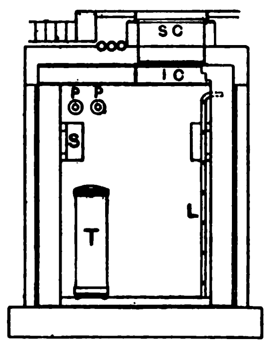


Fig. 43.

selection of and attention to the meters, there still remain the unavoidable losses. These are principally heating or C^2R, known as "Copper" losses, and transformer losses on converted systems which on light loads are almost wholly "iron" losses. The iron losses of alternating current transformers may amount to 3 or 4 per cent. of the maximum output. An alternating system has its highest efficiency on a high load factor, whereas a direct current is at its best on a low load factor. The losses on an alternating system principally depend, therefore, upon the "iron" loss in the transformers. The iron loss can be

reduced at the expense of an increase in the copper loss: thus high load factor or "power" transformers have usually a small copper and a comparatively large iron loss, whereas a "lighting" or low load factor transformer has these conditions reversed. A large copper loss involves a drooping characteristic and bad regulation, and necessitates transformers being run below their maximum output for reasonable uniformity of pressure.

To elucidate these points, assume that a system has a maximum load of 1,182 kilowatts with 1,500 k.w. installed transforming capacity. From an average load curve it will be found that about 4,400 units per diem may be sold, 1,100 units represent the iron loss, and 140 units the copper losses, giving an efficiency (5,640 units approximately being delivered to the mains) of between 75 and 80 per cent.

The large iron loss is caused by the whole of the transformers being continuously connected to the mains, and the magnetization power being taken throughout the twenty-four hours, although a useful output is only called for during three or four hours during this period. Some engineers accordingly disconnect such transformers as can be spared from the mains during the hours of light load, in the same manner as engines are disconnected and shut down during the daylight hours. Transformers scattered over a large area are much more difficult to deal with than engines which are congregated within one building. Moreover, the making and breaking of H.T. circuits or the interposing of coils is liable to create trouble, and transformers allowed to cool daily are prone to breakdown on being reconnected. But if the transforming capacity at work could be maintained somewhere near full load, the efficiency of an alternating system would be raised to

something over 90 per cent. The mere change of old pattern inefficient transformers for those of modern design with small iron losses may mean all the difference between profit and loss. Although the units used in magnetization are produced on a high load factor, and therefore cost say only $\frac{1}{4}d.$ each, each kilowatt represents 8,760 units, or say £10 per annum. The cost of magnetizing current may easily run up to £1,000 per annum, and it must be remembered that the small day plants producing this are relatively less efficient than the heavy load evening sets.

The Reduction of Magnetizing Losses has been the object in designing relay-controlled and automatic switches on transformer systems. These deal with the all-day losses in one or other of two ways: either (*a*) they are operated or come into action when the load upon a transformer or bank of transformers falls below a certain percentage of full load and cut out transformers one by one or in groups, leaving the idle converters completely disconnected from both primary and secondary mains; or else (*b*) special windings are put on the transformers and the apparatus changes the connections and alters the mode in which the different windings are coupled up so as to keep the main magnetizing power a minimum.

A modification of the first method is to make the polarity of both terminals on primary and secondary windings the same in the case of those transformers it is desired to put out of action. The second principle is applied to multiple-wound transformers which can be made large, cheap, and efficient.

(*a*) The simplest solution of the problem is hand switching, which can be left to an attendant at a sub-station.[1]

[1] Illustrations of converters fitted with hand-switching gear are

(*b*) An advance upon this is pilot wire or relay control from the generating station, which may be arranged in a similar way to the automatic switching of continuous-current converters, already described, or the switches may be operated by pneumatic,[1] hydraulic, or other suitable means.

(*c*) Into a third class fall those methods which depend upon the duplication of circuits, one of which is switched off when desired, thus cutting out the transformers supplied from it. The secondary side of the transformer must then be disconnected automatically.

(*d*) Fourthly, the mains and transformers may be so arranged that, by altering their polarity or coupling, the effective output capacity may be changed.

(*e*) Lastly, the requisite changes may be left to the unaided control of purely automatic and mechanico-electrical devices, which act with large variation of load, and embody either (*a*) or (*b*) above.

The primaries of a number of banked transformers, or transformers run in parallel on the secondary mains, may be fed by two or more distinct high-pressure circuits which can be connected together at or near the generating station. By this means one or more of the primary conductors can be cut off, and some of the transformers disconnected entirely, while the secondary system is still supplied by the remaining ones.[2] This is effected by magnetic switches of the solenoid and core type, the solenoids being included in the high-

to be found in the *Electrical Review*, vol. xxxiv. p. 666, June 8th, 1894.

[1] Suggested by L. Penson, and also patented by the Westinghouse Company.

[2] Patent, Raworth & Geipel, No. 5,988, March 28th, 1892.

tension connection to each transformer primary; the contact and break is inserted in the corresponding transformer secondary,[1] and the low-pressure circuit is closed and opened by the flow or stoppage of current to the primary coil.

An alternative means of causing the secondary to be connected and disconnected at the proper times is to make use of the reversal of current;[2] when the primary is cut off from the feeding mains, the back current returning from the distributors will throw the contact of a suitably-designed switch-over, and, if suitably designed, such an appliance ought to work well.[3] Messrs. Medhurst & Hope Johnstone designed a switch to change over from a five to a thirty kilowatt transformer for the Bedford sub-stations.[4] An ingenious plan has been described by Mr. Whitcher, in which duplicate primary feeding is combined with a sort of three-wire system.[5] Particulars of these appliances were given in the first edition of this work.

Automatic Transformer Switches have been made by Mordey, Kapp, Ferranti, Tomlinson, Walton, and others. Very few are, however, to be found at work, and the same reasons that led to the disuse of the extremely ingenious devices of Edmunds and King in connection with secondary battery sub-stations, have restricted the number, and curtailed the manufacture of apparatus intended to control the coupling of transformers without the intervention of human intelligence.

[1] Patent, W. Geipel, No. 6,666, March 29th, 1893.

[2] Patent, W. Lowrie, No. 3,666, 1893.

[3] A full description, with illustrations, appeared in the *Electrical Engineer*, vol. xiv. p. 93, July 27th, 1894.

[4] *Electrical Engineer*, vol. xiv. p. 632, November 30th, 1894.

[5] *Electrical Review*, vol. xxxvii. p. 558, 1895.

Berry has proposed, instead of connecting large and small transformers in parallel and by means of automatic gear, to energize the one or the other as required by the load, to place the primary and secondary coils in series, and automatically short circuit the smaller transformer during hours of peak load. During light loads the smaller transformer would supply most of the power required and its coils would act as impedances in the circuit of the large one, so that the latter is magnetized by the same current which performed that function for the small one.

E.g. a 10 k.w. and 100 k.w. transformer in series.

10 k.w.	100 k.w.
No load loss, say, 90 watts.	900 watts.
Day light load.	Peak load.
Designed for small iron losses.	Designed for small copper losses.
Comparatively poor regulation.	Excellent regulation.
Say, 4% drop of pressure.	Say, $1\frac{3}{4}$% drop of pressure.

The most suitable transformer can then be provided to deal with the load, and the pressure regulation is improved, as during the period of heavy load the large transformer, having a small drop of pressure, is in circuit. This could not be economically used by itself, as the no-load losses would be greatly increased owing to the large magnetizing power. The improved regulation tends to create a feeling of satisfaction, with the supply, and also produces a larger sale of energy if watt. hour meters are used. The reduction of temperature in a sub-station follows a diminution in the iron losses of the transformers installed, and the copper losses are thereby reduced, while the over-load capacity is increased as the initial temperature throughout is less. Ageing is also less liable to occur.

The fact that a few large transformers can be used in sub-stations renders the alteration in number less necessary than where many of small output are installed.

It may be pointed out here that the cost of the energy dissipated by the iron losses is, after all, not to be taken at the average price per unit generated throughout the year, nor even at the increased cost of turning out an additional number of units equal to those supplied to the transformers connected without any secondary output. In all stations a reasonable-sized unit of plant must be run during the day to comply with the obligation to maintain a constant supply. The real cost of magnetizing is, therefore, merely the difference in fuel, water, and oil consumption, when the plant is supplying magnetizing current, compared with what it would be with the alternator disconnected, wages and salaries and other standing charges not being affected in any way. Thus it is clear that a reasonable difference in magnetizing power is of extremely little moment, and can hardly affect the works or total costs one way or the other. There is no doubt that, in the event of automatic apparatus being used, the best results are obtained by changing connections if the iron losses are large, and altering the number of active transformers if the load losses are predominant.

The Tomlinson apparatus[1] was provided with four sets of switches, the transformers being in five groups, of which one was permanently connected to the mains, and one to each switch. The groups, however, consisted of, say, 2, 4, 8, 16, &c., transformers, so that the putting on of each switch doubled the number of active transformers. The switches were thrown over by a sliding carriage, in the form of a double wedge, which ran backwards and forwards along the bed-plate of the machine, and as it passed each switch threw over a tumbling lever which struck the switch suddenly in or out of contact. Driving power was supplied by a couple of weights released by two electro-magnets.

S. Z. de Ferranti[2] used contact or relay mechanism, which, when

[1] Patent 11,883, July 29th, 1890.

[2] Patent, 1,050, January 20th, 1891.

the current in the low-tension circuit was low, completed a shunt circuit which put into operation an electric or other motor to open or close the converter contacts, and caused the switch for the converter contacts as it tumbled over to break the shunt circuit, whilst at the same time another contact in the relay switch was brought into position to be acted upon whenever another movement of the main switch became necessary.

The earlier pattern was wound in three sections in both primary and secondary; the current to the primary was taken through a relay which, when the current exceeded a given amount, caused a mercury contact to be made, switching in a small alternate-current motor. This was connected, by means of gearing, to one end of a strong helical spring, the other end of which was geared to the commutator spindle. The motor wound up the spring until a catch lifted, when the spindle was rotated through 90° quickly by the stored energy in the spring. The contacts were ordinary switch contacts, metal to metal. The later form eliminated the motor, and had a double solenoid and cores on the end of a rocking lever. The relay worked much as before. The contacts were mercury cups, and only double sections of the winding were provided.

With two sets of primary and secondary windings, the power-capacity of a transformer is reduced to one-quarter, and the iron or constant loss to one-third, with both windings in series, compared with the values when both are in parallel. With three sets the power is one-ninth, and the loss one-sixth of the maximum, and so on for higher subdivision.

Transformer Compensators are extremely simple and most useful on the three-wire system. If an alternate current transformer be provided with two sets of coils, of similar length of wire and number of turns, on a common core, then any current that may flow in one coil will induce a current in the other coil, and the ratio of transformation being unity, it is immaterial which coil acts as primary and which as secondary. Suppose that the two coils be connected in series and placed across mains at a pressure of 400 volts, and that a set of 200-volt lamps,

fixed two in series, be put in parallel with the transformer. It only requires a neutral wire to be run from the intermediate junctions of the lamps to the centre of the transformer winding to suit the arrangement to a three-wire system. When the loading on the two circuits is equal, the transformer will not affect the supply, and the only current flowing through it will be the magnetizing current representing a few watts, most

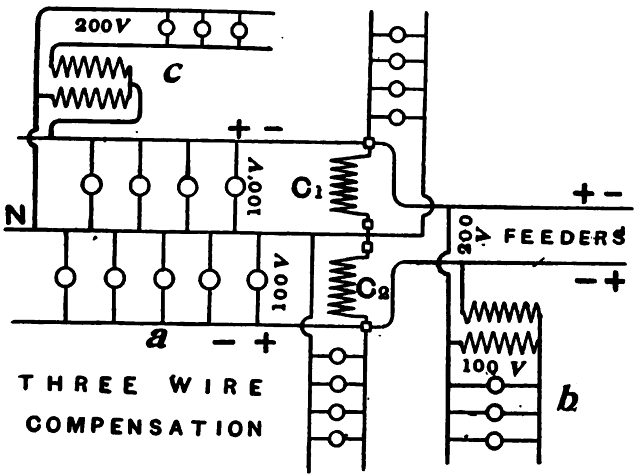


Fig. 44.

of which is spent in maintaining the induction in the core, and all of which can be accounted for by hysteretic loss, copper loss and Foucault currents. These are capable of being reduced to a very small quantity by properly proportioning the parts, and by using the most suitable grade of iron. When the loads on the two sides of the three-wire system are unequal, the pressure on the most heavily-loaded side will tend to fall, and the transformer

will transfer energy from the side that is least loaded to that most so, with the result that a balancing action is introduced, and the pressures on the two sides will be maintained very closely at their normal values. This method of balancing was suggested and patented some ten years ago by Messrs. T. Tomlinson and J. E. H. Gordon.

Fig. 44 gives three examples of a transformer compensator. In *a* two 100-volt circuits are balanced by the coils C_1 and C_2 wound together on a common magnetic core. In *b* only one side is loaded, i.e. the transformer is converting from 200 to 100 volts. This arrangement is commonly called an auto-transformer[1] or economy coil. In *c* the apparatus is employed to convert up from 100 volts to 200 volts, and this may be regarded as a case of boosting, as it is evidently equivalent to a transformer in which a part of the coil acts as a primary to the other part as secondary. The General Electric Company, U.S.A., brought out a system, about 1887, in which four coils were wound on the same iron core, the coils were connected in series across a 300-volt alternating current circuit, so as to give four circuits of 75 volts each. This compensator regulated excellently, and provided a means of supplying a five-wire alternating current system.

Double-current Generators supply alternating and continuous current from one armature. Such a machine is similar in most respects to a rotatory converter, and, as it delivers alternating current at a low pressure, the addition of step-up stationary transformers is requisite to enable a high-pressure transmission line to be fed. The generator may be a multipolar field magnet with a drum

[1] See also description of "a shunt transformer," *Journ. Soc. Tel. Eng.* vol. xviii. p. 297, 1889.

armature from which tappings are taken off to slip rings. Then the relationship between the continuous and alternating pressures and currents are—

$$\frac{\text{Alternating volts between}}{\text{Adjacent slip rings}} = \frac{1}{\sqrt{2}} \text{ Cont. E.M.F. Sin } \frac{\pi}{\text{Number of slip rings.}}$$

If the continuous-current and pressure values are taken as unity, then the alternating factors will be:—

		Current to line.	Pressure on line.
Two phase ...	...	·707 amp.	·5 v.
Three phase	...	·943 ,,	·612 v.

Regulation must be effected by boosting on the alternating circuit outside the generator. The generator can be loaded up with continuous or alternating current or both, simultaneously, up to the full load of the armature. The regulations and connections outside the generator are identical with continuous and alternating systems respectively.

Monocyclic System.—A system which attracted considerable attention a year or two ago was known as the monocyclic system. It is a single-phase distribution system, consisting of two wires with the addition of a third wire known as a teaser wire, the latter carrying an intermediate current, and is used in combination with the mains for running polyphase motors. As the mains themselves can be used for lighting without being disturbed by the motor current, the arrangement would appear to be a very suitable one for general central station work.

Polyphase Systems.—The extended use of alternating current systems has resulted in the development of polyphase practice. The generators used for the production of polyphase currents have their coils so wound that the

phases reach their maxima in rotation, or one after the other. In the case of two-phase generators the pressure and current in one phase is 90°, or one-quarter of a cycle

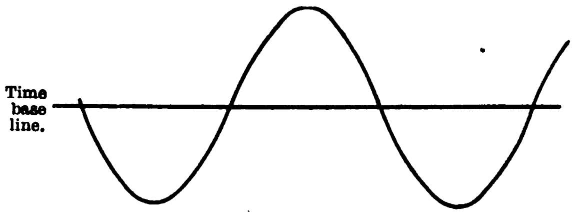


Fig. 45.—Single-phase alternating current.

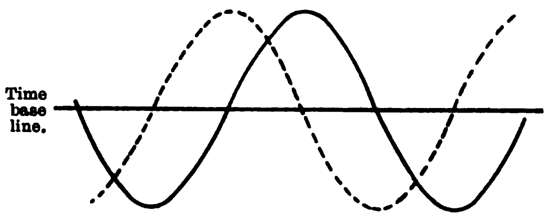


Fig. 46.—Two-phase alternating current.

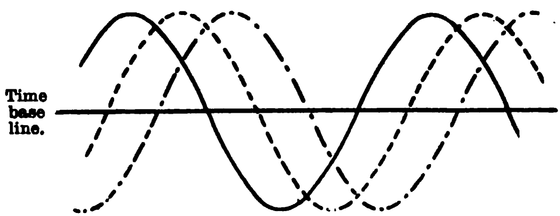


Fig. 47.—Three-phase alternating current.

behind the other, and when one wave is at its maximum the other is at its minimum, as shown in fig. 46.

With three-phase generators the waves follow each other at an angle of 60°, or the sixth part of a cycle. If the armatures of two single-phase generators are coupled rigidly together in such a manner that their respective

phases follow each other at an angle of 90°, a two-phase current may be obtained from the combination, while three such generators whose phases follow each other at an angle of 60° would be available for three-phase supply. It is hardly necessary to state, however, that such an arrangement would be more costly than a machine specially wound for polyphase currents.

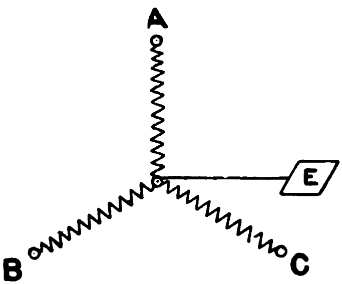
Generally speaking, all that has been said respecting single-phase alternators, as far as construction and management are concerned, applies to polyphase machines. Running in parallel, which is practically essential to all central station supply undertakings, can be performed with polyphase generators almost as readily as with single-phase machines, and the methods of synchronizing and coupling are similar. Care, however, has to be taken that similar phases are connected, and that each is in synchronism before coupling. The flexibility of the single-phase alternating system is maintained and probably increased by the use of polyphase currents. One system of polyphase can be readily changed to another by means of transformers specially wound and coupled,[1] while the possible combinations of generation, transmission, and distribution are almost endless. There is no doubt that for large power transmission schemes over long distances the polyphase systems are a great advance upon single-phase, but it is questionable whether for ordinary central station supply the latter system is inferior, bearing in mind the increased complication of the former.

Among the advantages of polyphase working is the reduction in cost of the plant. Thus a three-phase generator is only about two-thirds the cost and weight of

[1] See "Standard Polyphase Apparatus and Systems," M. A. Oudin.

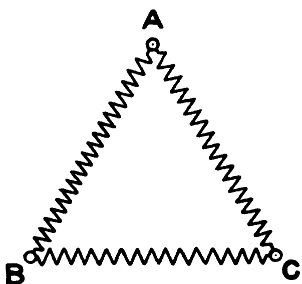
a single-phase machine of the same output. Similarly, a three-phase is cheaper and lighter than a two-phase. The copper in the mains is utilized to better advantage, as what may be looked upon as its infinitesimal load-factor is greater, the whole of the magnetic and electric parts being actively employed for a longer period as the phases become more numerous. The principal benefit of two-phase is its applicability to single-phase systems which have to be converted without complete reconstruction.

There are two modes of connecting up-apparatus on



STAR OR Y WOUND

Fig. 48.



MESH OR Δ WOUND.

Fig. 49.

three-phase systems, figs. 48 and 49, the star or Y and the mesh or Δ. With star-winding the pressure between earth and the machine windings is under 60 per cent. of that between the circuit conductors, and on transformers constructed with this winding an advantage is gained, as they are therefore less expensive than the mesh winding. The reason which has led to an extensive adoption of the star connection is the security obtained by earthing the central point. With Δ-wound generators harmonics on the current waves are apt to cause trouble, and idle currents may circulate in the closed triangle of the armature

winding. On the transforming side, if separate transformers are installed, this arrangement has the advantage that the breakdown of one does not interrupt the supply, as the others will maintain a three-phase supply. Trans-

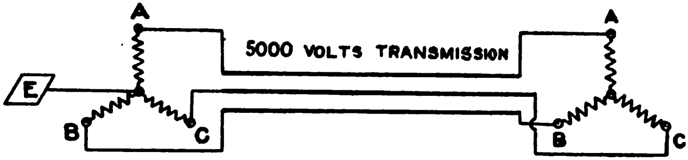


Fig. 50.—Star polyphase transmission.

formers wound in either way can be connected in parallel. From sub-stations supplied with two or three-phase alternating current at high pressure, either of the two kinds of supply can be given, direct or alternating. The

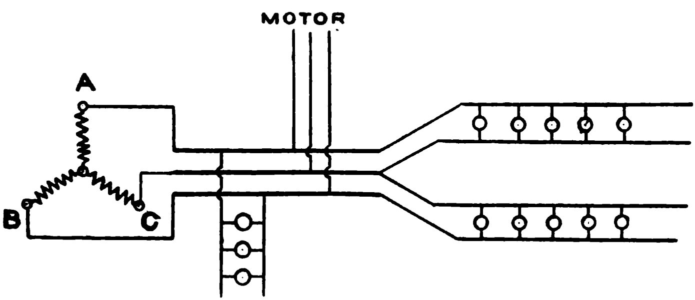


Fig. 51.—Star polyphase distribution.

alternating distribution does not involve any special apparatus. Multiphase transformers, taking the place of single-phase and three-core or four-core l.t. feeders and distributors cover the area of supply from each substation, as shown in figs. 50 and 51, for star transformer

connections respectively. The growth and development of multiphase working has been due to the facility for converting to continuous current before distributing. By this means most of the erstwhile continuous-current systems are extending their plant and dealing with the rapidly increasing load, and all tramways of any importance are operating in the same way; while, without it,

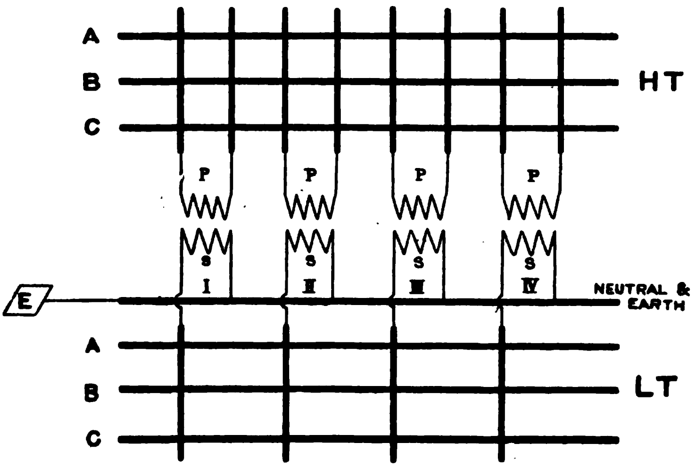
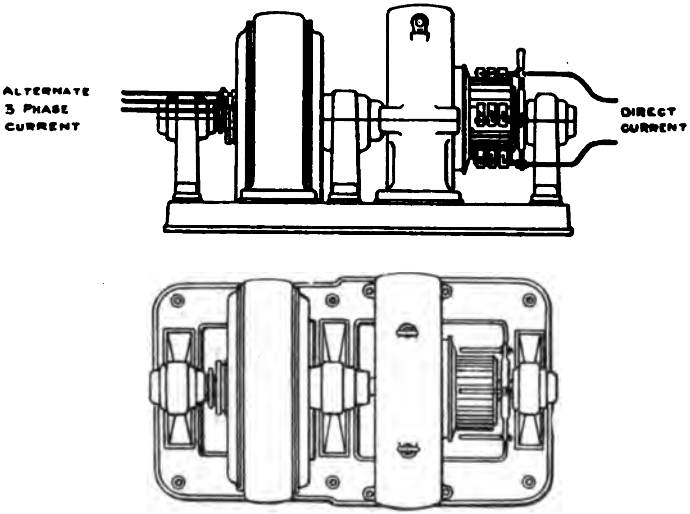


Fig. 52.—Polyphase sub-station connections with single-phase transformers.

the tube railways would have remained merely examples of what electric traction might do if transmission to long distances were possible.

Single-phase transformers may be used on two and three-phase systems, one being connected across each phase or multiple-coil transformers coupled up similarly to the alternators. The connections may be Δ on the h.t. side and the same on the low, star on both sides, or Δ on

one and star on the other. Multiple-wound transformers are cheaper, but a complete spare must be provided; whereas by using single-phase, a spare can be used to replace a defective one on any phase. A typical arrangement of sub-station switch-boards is shown in fig. 52, in which means of interchanging the transformers are pro-



Figs. 53 and 54.—Three-phase to direct current motor generator.

vided. The three-phase transformer has a slightly lower efficiency than single phase, but the difference is not sufficiently great to influence the choice. A multiple-wound transformer possesses a great advantage in equalizing the pressure on an unbalanced load. This is, of course, absent where the coils are wound on separate cores.

Polyphase Motor-generators are merely combinations of

an alternating motor—either synchronous or induction—on the same shaft with a direct-current machine. They save the cost of stationary transformers as they can be supplied directly by the high-pressure lines. Such combined sets can do everything that a motor or a dynamo can do. The regulation on the continuous-current side is entirely independent of the alternating supply, and the motor can be constructed to work at higher frequencies than would be suitable for rotaries. The transformation of power along the shaft, first into mechanical and back to electrical energy, slightly reduces the efficiency of the combination compared to rectification. Synchronous motors are started upon the continuous-current side, and then thrown on the alternating supply. Induction or non-synchronous combinations are started in the same way as an ordinary motor.

Rotary Converters.—The choice lies between rotary converters and motor generators (figs. 53 and 54) when the alternating supply has to be delivered to the distributing mains as continuous current. The rotary is cheaper in first cost and to maintain, it is rather more efficient, takes up less space, stands overloads well, and, in some respects, it is simpler. It is, on the other hand, sensitive to pressure variations. The incoming h.t. supply is transformed down by stationary transformers, and is then converted by the rotary converters to direct current. A low frequency is imperative if rotaries are selected, the commutation difficulties and trouble on parallel running being reduced as the frequency is diminished. A rotary is in principle an armature provided with both commutator and slip-rings run in a direct-current field. The incoming multiphase current is taken to the slip-rings and is delivered at the proper moment to the appropriate commutator

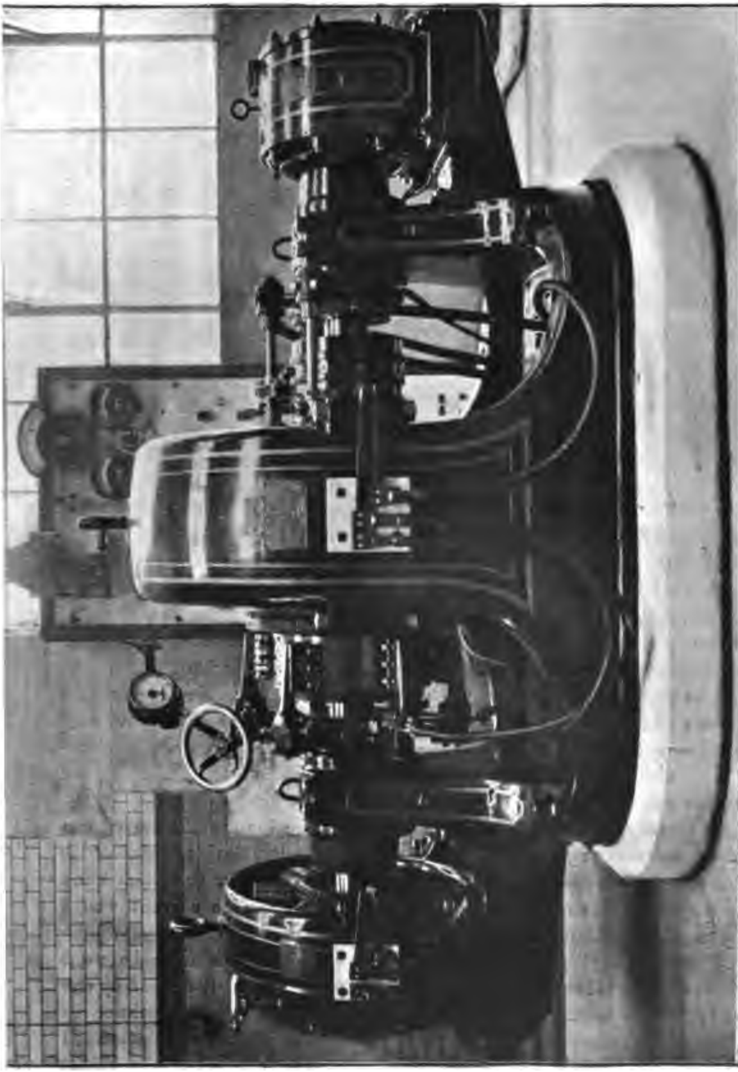


Fig. 55.—Rotary converter with exciter, starting motor and switchboard.

segment, being taken off as a continuous current with but slight sinuosities or departures from a steady value. It is therefore merely an amplification of a rectifier such as the Ferranti described in a later chapter. The ratio of transformation between the two sides is with three-phase about 100 volts direct to 60 volts alternating. The efficiency varies from about 85 to 88 per cent. at half load to 91 or 92 per cent. at full load.

Induction motors run on a multiphase system act as governors, and tend to steady any rotaries there may be on the same mains.

A rotary converter of 250 kw. capacity is shown in fig. 55, to deliver continuous current for tramway service at a pressure of from 500 to 550 volts, operating at a synchronous speed of 500 r p.m. on a 25 period three-phase circuit with a ratio of 5,000 volts to 330. The efficiencies of such a (Westinghouse) rotary is not less than 90 per cent. at half load, 92 per cent. at three-quarter load, and 93 per cent. at full load. It is capable of developing its full normal rated capacity for 24 hours continuously without heating in any part to exceed 40 degrees C. above the temperature of the surrounding atmosphere, and 25 per cent. overload for two hours or 50 per cent. overload for ten minutes without injurious heating or sparking, while an overload of 100 per cent. is not sufficient to pull such a machine out of synchronism.

The three collecting rings are connected to the armature windings at points 120 degrees apart. The pole tips are shielded to counteract any tendency to "hunting," due to variations in the frequency of the alternative current, while the fields are over-compounded to give a rise of 10 per cent. in voltage between no load and full load.

A three-phase induction motor is mounted on an extension of the shaft for starting the rotary converter. This method of starting is found to be the best, since although the rotary converter, which runs as a synchronous motor, may be started as such, a large current would be required to start it as a motor.

The characteristic of a rotary converter which enables it to be used as a motor is taken advantage of in this instance, as will be noted by the 15 kw. series wound booster carried on a bracket bolted to the bed-plate of the rotary, having its armature mounted direct on the extended shaft.

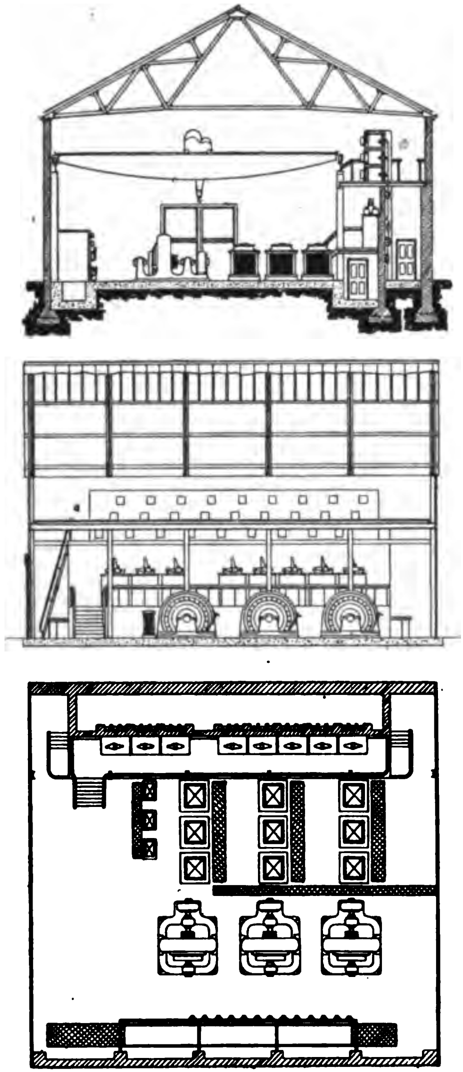


Fig. 56.—Example of sub-station with rotary transformers.

A sub-station with rotaries on a polyphase system is shown in fig. 56. In the elevation the h.t. switch gear is on the right hand, next come the stationary transformers, then the rotaries, and on the left the low-pressure continuous current board controls the out-going circuits. The mode of separating the various elements of the high-tension gear is depicted, the board being in two tiers, the operations being controlled from below, and the actual apparatus for breaking circuit, &c., being located out of reach, but accessible when required by mounting the ladder seen on the left of fig. 56.

Polyphase Distribution.—With two-phase distribution, three conductors or four conductors can be used in the former case, one conductor forms an intermediate to the other two, and in the latter the phases are separated. With three-phase three or four conductors can also be employed, or the phases can be split on six conductors. On two phases consumers for lighting are placed on each phase, and these are balanced for load, the same applying to three phases, only in this case there are three groups of consumers. By using four conductors on three-phase the system acts like a three-wire distributor, the pressure variations between consumers, due to want of balance, are reduced, and one phase can be interrupted without seriously affecting the other phases. The only objections to the four-conductor method are the expense entailed in the extra conductor and its fittings, and the higher pressure introduced into the cable, which is almost always made with multiple cores in one lead sheathing.

CHAPTER VII

STEAM GENERATORS AND PLANT

Boilers.—Considerable diversity of opinion naturally exists as to which is the best and most suitable type of boiler for electric lighting purposes. Each particular form has its votaries, frequently irrespective of the particular conditions under which such boilers have to work. Boilers used in central stations may be briefly divided up into three classes :—

(*a*) *Lancashire or Cornish type;* having large steam capacity, and consisting of a spacious outer shell with one or more flue-tubes passing through, around which the water circulates.

(*b*) *Locomotive or marine type;* consisting of a nest of small tubes within an outer shell, the water circulating between the tubes, and the heated gases passing through them.

(*c*) *Water-tube type;* consisting of a number of tubes around which the heated gases pass and through which the water circulates. These tubes are connected to one or more comparatively small steam drums.[1]

Lancashire or Cornish Type (see fig. 57).—As a general rule, for all-round purposes, the Lancashire type of boiler

[1] Other forms of boilers are simply combinations of two or more of those mentioned.

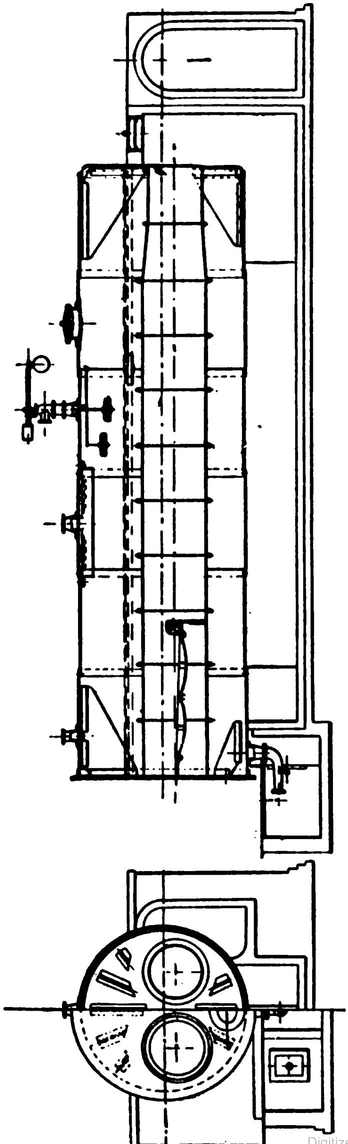


Fig. 57.

is probably most suited to the requirements of electric lighting. They are simple in construction, and as they possess great steam capacity, they are not liable to rapid fluctuations in pressure—a matter of considerable importance in an electric lighting works where the load on the engines frequently varies, and which, in a boiler possessing but small steam capacity, would produce fluctuations in the pressure and consequently variations in speed unless the engines were well governed, and in any case making electrical pressure regulation difficult. One of the chief drawbacks to the use of Lancashire boilers is that the pressure can only be raised slowly, and should a heavy load come upon the engines unexpectedly, stand-by boilers cannot be got to work at once, and a lowering of the speed of the engines would probably ensue unless special precautions were taken to prevent it.

The cleaning of a boiler of this type is a comparatively simple matter, as all the surfaces are large and easily accessible, and the removing of the scale[1] is therefore not so difficult as in the case of tubular boilers, where the tubes are small in area and great in number.

It appears to be very difficult to construct a boiler of this class in such a manner as to entirely prevent unequal expansion with rapidly varying duty, and although it may be designed and built by first-class makers and the greatest care taken by the user to prevent extremes of temperature, leaky rivets and seams—particularly about the boiler front and the furnace end of the flue-tubes—are not uncommon, and when the water contains chlorides it frequently gives considerable trouble and requires constant attention.

Priming (the carrying over of water with the steam

[1] See "Hard Feed-water" (p. 216).

into the steam pipes) is largely avoided by the use of this type of boiler, provided the water is kept at its proper level and no attempt is made to force the boiler beyond its normal evaporative capacity. Unfortunately, it requires considerable floor space, both for the boiler itself and also for its flues, and when it is necessary to curtail the size of the building on account of the cost of land or for other reasons, some other type is usually adopted.

In the event of collapse of a flue-tube through overheating or other cause, repairs can only be effected by properly skilled men, and in some cases it may be necessary to unseat the boiler in order to do the necessary work.

In course of time the plates of the shell and flue-tubes get thin through constant wear, and it becomes necessary to reduce the working pressure; it is therefore advisable to provide boilers built for a greater pressure at first. Reducing the pressure would be a serious matter in most electricity works.

The chief advantages and disadvantages of the Lancashire type of boiler are briefly as follows:—

Advantages.	*Disadvantages.*
(*a*) Simple in construction.	(*a*) Slow steaming.
(*b*) Easily cleaned and examined.	(*b*) Liability to leakage through unequal expansion.
(*c*) Great steam capacity.	(*c*) Great floor space required.
(*d*) Not liable to prime.	(*d*) Specially skilled men required to effect repairs.
	(*e*) Reduction of working pressure necessary in time.

Fig. 58 illustrates the front of a Lancashire boiler, with fittings as used in modern central stations. A is the shell of the boiler; B, the furnace fronts; C, levers for operating the dampers; D, check valves on the feed-water inlets; E, muffles over the forced draught steam nozzles; F, steam supply pipes to forced draught; G, manhole-

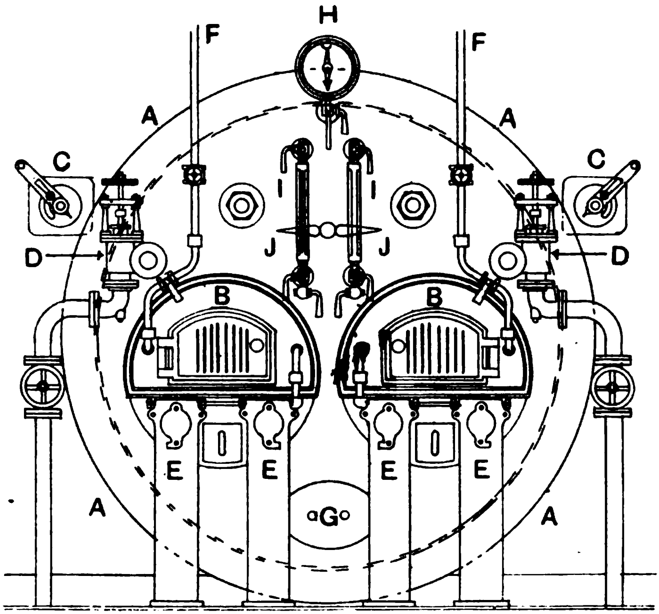


Fig. 58.

cover; H, steam-pressure gauge; I, water gauges; J, water-level pointers.

Locomotive Type (see fig. 59).—This boiler is frequently used, in preference to the Lancashire or Cornish type, when it is necessary to economize floor space. It requires no setting or flues, it being fixed at once on its own bed-

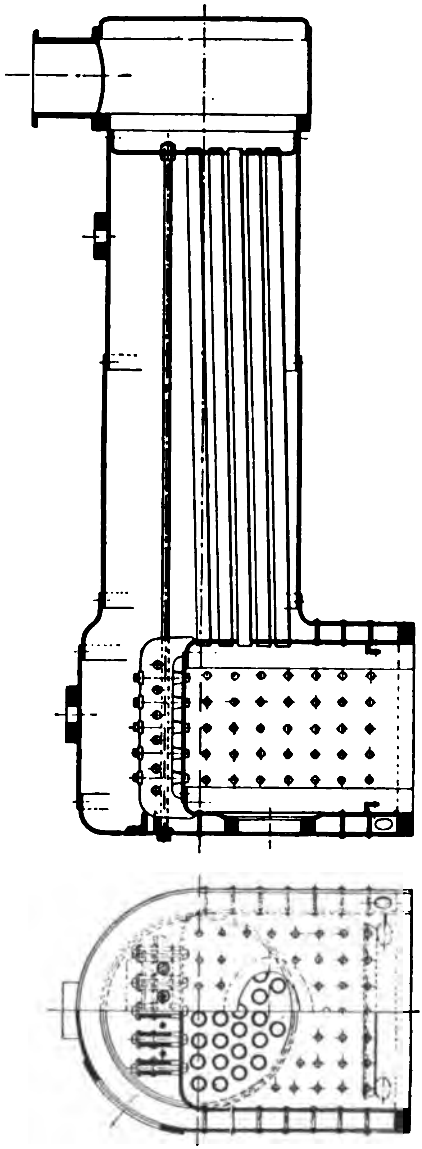


Fig. 59.

plate in some convenient position where the smoke may be carried from its smoke-stack or funnel either direct into the air or into the chimney of the works.

Its steam capacity is much less than that of the Lancashire type, and it therefore requires more careful stoking and is liable to fluctuations in pressure. For the same reason it is rapid steaming, and the pressure can, if desired, be raised quickly. In the event of a tube being ruptured, it is sometimes possible to plug it temporarily and so continue running until the load is off, when it can be withdrawn and a new one inserted.

In consequence of the large number of tubes, it is somewhat difficult to clean, particularly if the scale[1] formed on the tubes due to hard water is very hard, as is frequently the case. The tubes are so closely packed together that it is a most difficult matter to get a scraper between them, more especially as they are not accessible from either end.

The fire-box or furnace being rectangular in shape and forming part of the boiler, it is necessary to have the sides stayed in order to withstand the pressure. The stays, which are usually of copper and the riveted heads of which are in contact with the fire, are sometimes a source of trouble in consequence of the heads burning away and causing leakage. Electrolytic action between the copper stays and the steel plates is sometimes responsible for leakage.

The corners of the fire-box also frequently give trouble on account of the awkward riveting necessary, and the consequent difficulty of making a sound joint in the first place, and of caulking it should leakage result later.

As the shell-plates tend to get thin, in time a re-

[1] See "Hard Feed-water" (p. 216).

duction of pressure becomes necessary, as in the case of the Lancashire type, though perhaps not to the same extent.

The chief advantages and disadvantages of the Locomotive type may be briefly summarized as follows:—

Advantages.	*Disadvantages.*
(*a*) Small floor space required.	(*a*) Small steam capacity, and consequent liability to fluctuation in pressure.
(*b*) Quick steaming.	(*b*) Not easily cleaned or examined.
(*c*) Ruptured flue-tubes easily replaced.	(*c*) Liability to leakage at stays and corners of fire-box.
	(*d*) Reduction of pressure necessary in time.

Water-tube Type.—The water-tube type of boiler is very much in favour amongst electrical engineers on account of the rapidity with which steam can be raised, the comparatively small floor space which it occupies, and the limitation of risk of serious explosion in the event of overheating.[1]

Unfortunately it possesses very small steam capacity, and consequently very careful stoking is necessary to avoid fluctuations in pressure.

On the other hand, in the event of an unexpected load coming on the engines, the water-tube boilers are most useful, as the pressure can be raised, and evaporative duty increased in a few minutes, thus preventing the lowering

[1] See "Causes of Explosion" (p. 191).

of the speed of the engines, and consequent variation in the supply.

Where very hard feed-water is used, the water-tube type of boiler presents considerable difficulty in cleaning, and if scale once forms on the interior of the tubes there is no means of getting at it except by the use of a scraper, and the process of cleaning is therefore a tedious and expensive one.

As the steam drum is small in diameter (figs. 60 and 61), and the circulation of the water very rapid, priming is not infrequent, the water being carried over with the steam causing very considerable trouble, more particularly if the boilers are forced.

In London, and other places where the load is liable to be affected by unexpected fogs, some form of quick steaming boiler, such as the water-tube, would seem to be almost a necessity, hence the practice of some engineers of combining the two types of boilers, namely, the Lancashire and water-tube, in the works which they design.

One important advantage possessed by the usual forms of water-tube boilers is that, in the event of a tube being ruptured, due to overheating or other cause, it can be withdrawn and replaced with a new one by an ordinary fitter.

It is claimed for this boiler that reduction of pressure is never necessary in consequence of the tubes or plates getting thin, as all the tubes can be replaced when signs of wear are observed. But it is evident that sooner or later the plates of the steam drum will become reduced in thickness, although they will probably last much longer —on account of the small diameter of the drum—before reduction of pressure becomes necessary than in the case of the Lancashire type.

As the boiler is hung from girders, and the tubes are therefore free to expand and contract, it is not liable to leakage or fracture through differences in temperature, and it can therefore be cooled down or fired up much more quickly and with less risk than boilers of the shell type.

The chief advantages and disadvantages of the Water-tube type are briefly as follows :—

Advantages.	*Disadvantages.*
(*a*) Rapid steaming.	(*a*) Small steam capacity.
(*b*) Safety.	(*b*) Not easily cleaned.
(*c*) Small floor space required.	(*c*) Liable to prime.
(*d*) Repairs easily effected.	
(*e*) Reduction of pressure not necessary through wear.	

Vertical boilers are sometimes used for the purpose of economizing floor space. These may be of the Lancashire or Cornish shell type, with central flue-tubes, or of the multi-tubular locomotive type; but by far the most popular form of vertical boilers are of the water-tube variety.

Unfortunately the majority of these are made with curved or bent tubes, rendering proper inspection difficult, if not impossible. Of course, the makers argue that inspection is not necessary, as the circulation is so rapid and the scouring effect so pronounced that the tubes never scale, even with the hardest water. Most station engineers, however, would probably prefer to be able to thoroughly inspect every part of a boiler rather than depend upon the scouring action.

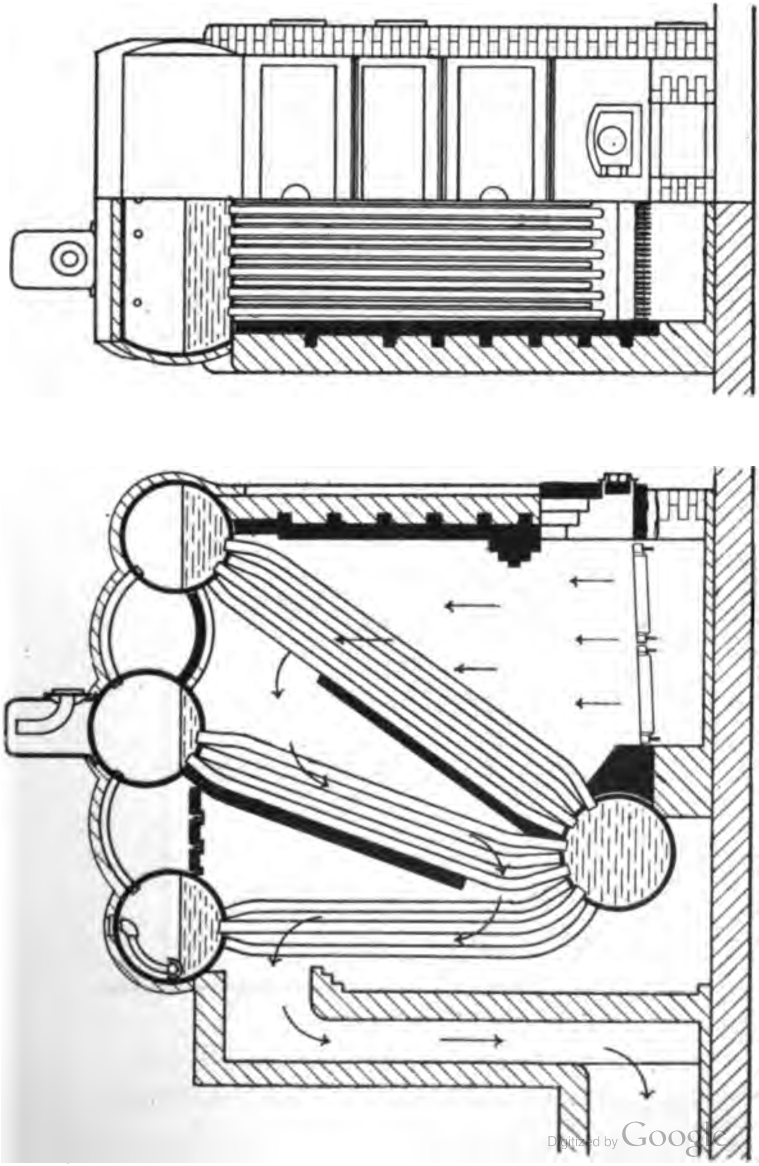


Fig. 62.

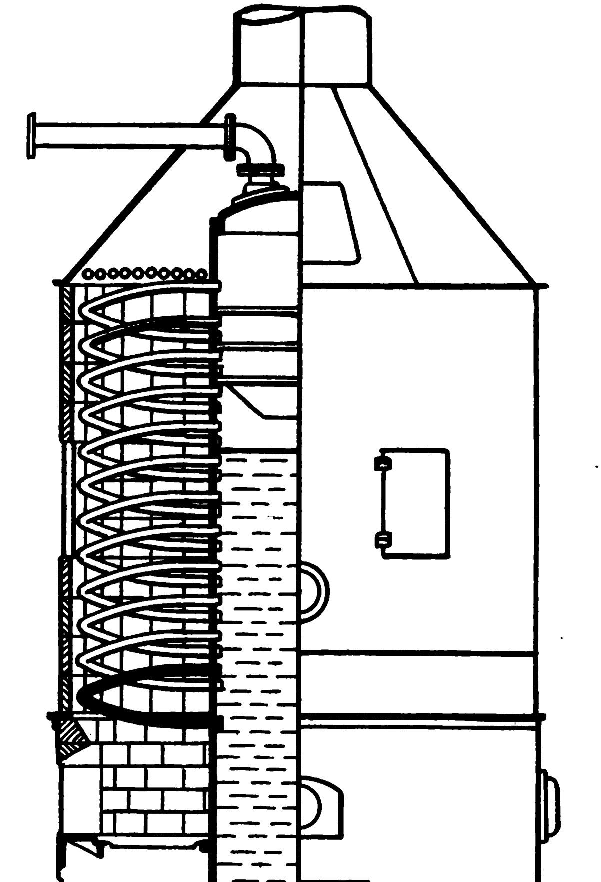


Fig. 63.—Climax sectional elevation.

Figs. 62, 63, and 64 show sectional elevation of a Sterling, Climax, and Hornsby boiler respectively. It

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will be seen that the two first have curved tubes, and the last straight tubes.

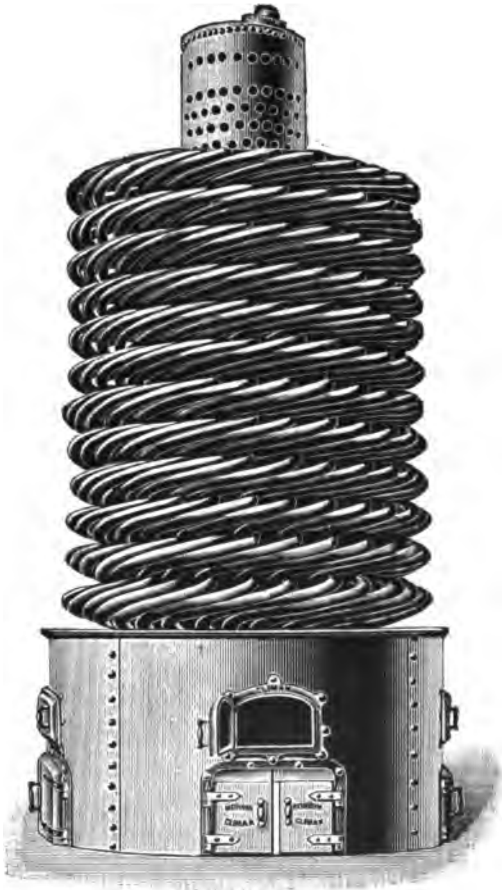

Fig. 65.—Climax elevati n of tubes.

Boiler Fittings and Accessories.—Boilers used for electric lighting, no matter of what type, are now usually

provided with a full set of fittings or mountings, including duplicate feed valves, high and low water alarm, duplex safety valves, isolating valves, &c.

The high and low water alarm consists of floats attached to a blow-off valve, and so adjusted that should the water in the boiler fall below a given level, steam at once escapes, or a whistle is blown; similar results take place should the water rise too high.

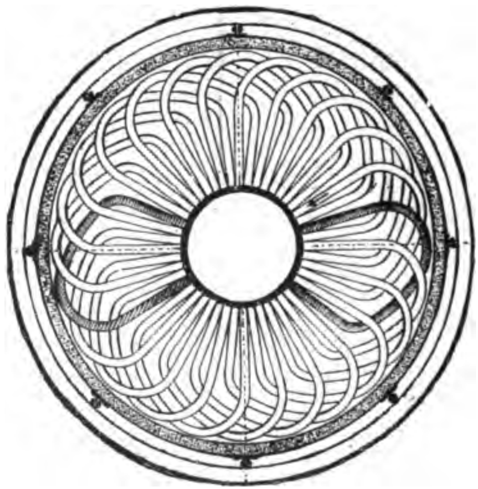

Fig. 66.—Climax plan of tubes.

The duplex safety valves generally consist of two valves on one seat, the one being a spring valve and the other a dead-weight valve, thus reducing the risk in the event of one valve failing to act should the pressure in the boiler rise too high.

The isolating valves are a comparatively recent introduction, and are intended to ensure that every boiler does an equal amount of work. It is in principle a back-

pressure valve, allowing free exit of steam from the boiler to which it is attached, but checking or entirely preventing the flow of steam from the steam pipes into the boiler.

Where a number of boilers are connected to a steam main, it is not possible to tell whether each boiler is doing its fair amount of work, as the steam pressure gauges all show the same pressure, the boilers being connected together. Where the isolating valve is used, however, should one boiler through inattention be allowed to shirk its work, the valve would immediately close, and the pressure gauge on that particular boiler would then show a reduced pressure.

The water gauges are usually provided with check valves which automatically prevent a rush of steam or water should a glass be accidentally broken.

The pressure gauge is usually provided with a large dial with bold prominent figures, and the pressure at which the safety valves are set to blow off is generally indicated on the dial.

The following is a brief summary of the chief fittings or appliances now generally used :—

(*a*) High and low water alarm.
(*b*) Duplex safety valves.
(*c*) Isolating valves.
(*d*) Water gauges.
(*e*) Steam-pressure gauge.
(*f*) Main valve, feed valves, blow-down valve, &c.

Inspection.—Too much care cannot be taken to ensure facility for the proper inspection of boilers, and this should be frequent and thorough. There is no doubt that many serious accidents might have been avoided had this been the rule. The practice of lagging a boiler with non-

conducting composition in contact with the shell prevents the proper inspection of the plates and rivets, unless, of course, the whole of the lagging was removed, which would be an expensive matter, as new lagging would have to be provided every time. In order to overcome this difficulty an arrangement known as an overtop chamber has been introduced.

As will be seen in the diagram (figs. 67 and 68), which takes as example one of the Lancashire type, the outer walls of the boiler are raised to a height of some twelve

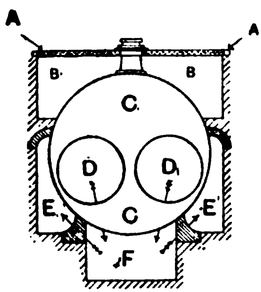

Fig. 67.

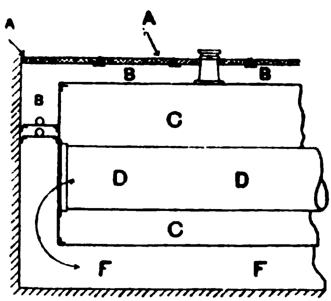

Fig. 68.

A, Plates carrying non-conducting composition; B, air space for examination; C, shell of boiler; D, flue-tubes; E, side flues; F, under flue.

or eighteen inches above the shell. Angle-iron joists are then laid across the two walls and upon these are fixed plates of iron. Holes are left in the plates for the pedestals which support the valves and fittings to come through, the pedestals themselves being lengthened in order to allow of sufficient clearance between the plates and the crown of the boiler. The platform thus constructed is then covered with non-conducting composition, and a man-hole in the platform admits of entrance, so

that the whole of the upper portion of the shell can be minutely examined as frequently as is desired without interfering in any way with the lagging. Curved seating blocks are also often used in order that as little of the shell as possible is covered up. By the use of these blocks and overtop chambers, practically the whole of the outer portions of the shells can be easily inspected.

Causes of Explosion.—There is no doubt that in the past many explosions were due to *faulty construction*, insufficient allowance having been made for unequal expansion in different parts of the boiler, thus throwing undue strain upon the rivets, seams, and stays. A great deal of this trouble has now, however, happily been overcome, and with a boiler supplied by a first-class maker there need be but little apprehension on this account, provided it is properly treated. Even with the best constructed boiler leakage will result, and even grave risk be incurred, if it is subjected to rapid *variations in temperature*, and when it is taken off for cleaning or for any other purpose its temperature should be reduced as slowly as possible, particularly in the case of the shell type.

The method frequently adopted of cooling down rapidly by pumping in cold water should never be resorted to, and when it is required to put a boiler into use the fire should be raised gradually and as much time given as possible for the generation of steam.

Accidents sometimes occur due to the *water* in the boiler being allowed to get too *low*. The passages to the gauge glasses frequently get choked, more especially when the water is hard, and while the gauge may show several inches of water above the furnace crowns, the latter may be really above the water level and so get seriously over-

heated, with the result that the flue-tubes collapse. The probability of this occurring is much minimized by the use of the high and low water alarm. It is, however, a very good practice to see all the gauge glasses blown through every half hour. Over-heating of boiler tubes and furnaces sometimes takes place through the *formation of scale* [1] deposited from the water; the risk from this cause, however, can be reduced by blowing down the boiler through the blow-off valve, and lowering the water half an inch or so every day. By this means a part of

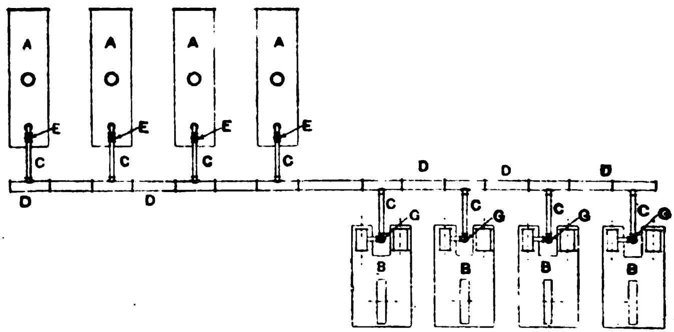

Fig. 69.

A, boilers; B, engines; C, supply pipes; D, main steam pipe or receiver; E, stop valve on boiler; G, stop valve on engine.

the deposit is removed from the boiler in a finely divided state, and before it has hardened into scale.

Wilful *tampering with safety valves* on the part of the men in charge, as well as undue wear on the shells and tubes being allowed to pass unnoticed (*lack of proper inspection*) has been the cause of many serious accidents. The former can be prevented by proper supervision and

[1] See "Hard Feed-water" (p. 216).

the use of "dead-weight" valves, and the latter by frequent and careful inspection.

When the condensed steam is used over again in the boiler there is always the risk of *oil and grease* being carried into the boiler, and should this occur in any appreciable quantity over-heating of the tubes may result.

Steam Pipes.—The arrangement of steam connections between boiler and engine would appear to present but little difficulty, and yet probably there are almost as many different arrangements of steam pipes as there are central stations, each possessing its merits and disadvantages, and it may not be out of place to briefly review some of the arrangements adopted.

The first arrangement (figs. 69 and 70) is that in which all the boilers are connected to steam pipe or receiver, to which also are connected the supply pipes to the various engines. This form, which has the merit of simplicity, enables any boiler to be shut down for cleaning without stopping the supply to any of the engines (provided of course that there are reserve boilers). It, however, presents many disadvantages, the chief being that in the event of damage to the receiver pipe the whole system is disabled until repairs can be effected; indeed, the blowing of a steam joint necessitates shutting off steam from the whole

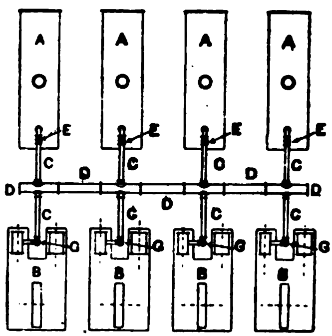

Fig. 70.

A, boilers; B, engines; C, supply pipes; D, main steam pipe or receiver; E, stop valve on boiler; G, stop valve on engine.

system before the joint can be re-made, thus stopping continuity of the supply of electricity to the consumer.

Advantages.	*Disadvantages.*
(*a*) Simplicity.	(*a*) Cannot be repaired without interrupting the supply.
(*b*) Any boiler can be taken off without affecting the engines.	(*b*) Large surfaces and consequently great risk in case of accident.
	(*c*) Large surfaces and consequently considerable radiation.

The second arrangement (fig. 71) goes to the other extreme, each boiler being connected direct to one engine, and not in any way connected with its neighbour. For simplicity this probably could not be surpassed: it does away with the large and dangerous receiver, any damage occurring to the supply pipe between boiler and engine would disable that particular engine only, while losses due to radiation would be very small on account of the small diameter and short length of the pipes, and consequently the little surface exposed to the air. Its chief disadvantage lies in the fact that a larger reserve of both engines and boilers is rendered necessary than in the case of any

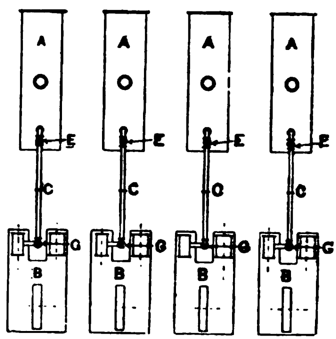

Fig. 71.

A, boilers; B, engines; C, supply pipes; E, boiler stop valves; G, engine stop valves.

of the other arrangements here described, as the following example will show.

Assuming a rank of four boilers, should No. 1 boiler be off for cleaning, and at the same time one of the other engines disabled from any cause, half the plant would be disabled, as there would be no means of supplying No. 1 engine with steam from the other boilers.

Advantages.	*Disadvantages.*
(*a*) Simplicity. (*b*) Short pipes small in diameter, and consequently little radiation. (*c*) Safety.	(*a*) Large proportion of reserve engines and boilers required.

The third arrangement (fig. 72) is that most frequently adopted in modern stations, and is known as the ring system. A main range or receiver pipe passes along by the boilers and thence to the engines, and returns on itself at the other end of the boiler range, thus making a complete ring or circuit. All the boilers and engines are connected to this range with stop valves between each boiler and each engine. Should it be necessary in order to effect repairs or other cause, a portion of the main pipe can then be shut

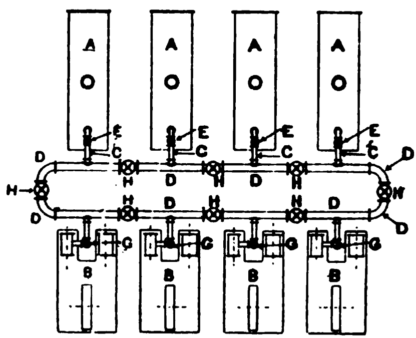

Fig. 72.

A, boilers; B, engines; C, supply pipes; D, main steam pipe (ring main); E, boiler stop valves; G, engine stop valves; H, stop valves on ring main.

off by means of the valves, and the supply be still given to the engines from the other side of the range, thus obviating the necessity of disabling any of the engines when the boilers are being cleaned.

It possesses the advantage that any boiler or engine can be shut down without affecting the others, while the risk of stopping the supply is practically eliminated. Unfortunately, a large number of valves is essential, and these frequently give trouble, to say nothing of the fact that the risk of opening or closing a wrong valve is thereby greatly increased.

The number of steam joints is also considerable, all of which may require frequent attention and repacking. The system necessitates a great length of pipe, sufficiently large in diameter to convey the steam from all the boilers to all the engines, or throttling and consequent trouble with the engines would result should it be necessary to shut off one side of the "ring" for any reason. The diameter and length of pipe necessary must allow of considerable radiation, and therefore condensation.

Advantages.	*Disadvantages.*
(*a*) Any boiler or engine can be shut down for repairs.	(*a*) Large number of valves and steam joints necessary.
(*b*) Very small risk of supply being interrupted.	(*b*) Great length of pipe of large diameter.
(*c*) Sections of pipe can be shut off for repairs.	

The fourth arrangement is shown in fig. 73. As in the case of No. 2 (fig. 71), each boiler is coupled direct to an engine by the usual supply pipe; the latter is, however,

extended back over the boiler to allow for the expansion of the auxiliary or equalizing pipe, to which it is also connected through a separate valve. Under ordinary circumstances, and when each engine is about equally loaded and each boiler doing equal duty, little or no steam passes through the auxiliary pipe, but should any boiler begin to shirk its work the supply of steam to its engine is made up by the other boilers through the

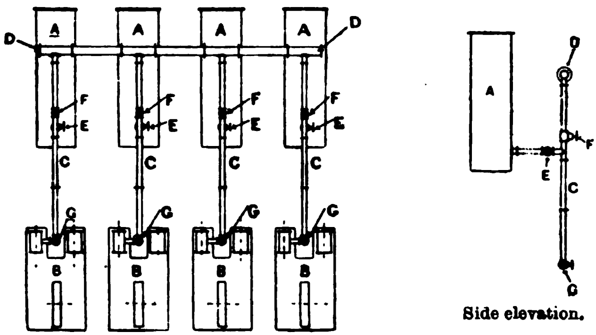

Fig. 73.

A, boilers; B, engines; C, supply pipes; D, auxiliary or equalizing pipe; E, boiler stop valves; F, stop valves to equalizing pipe; G, engine stop valves.

equalizer. Should one engine have less load than the others its boiler will supply steam through the auxiliary pipe to the other engines. When it is necessary to shut down a boiler for cleaning, its engine is supplied from the other boilers, and during the daytime or hours of light load the running engine can be supplied from its boiler direct, and, if deemed requisite or advisable, the equalizer can be shut down. Should the companion boiler to the running engine be off for cleaning or repairs any

other boiler can supply that engine through the auxiliary pipe.

Advantages.	*Disadvantages.*
(*a*) Small pipes and comparatively short length.	(*a*) Considerable number of valves, though less than in ring system.
(*b*) Very small risk of supply being interrupted.	
(*c*) Any boiler or engine can be shut down for repairs.	
(*d*) Simplicity as compared with the ring system.	

Expansion of Pipes.—In designing a system of steam pipes, too much attention cannot be paid to the question of expansion and contraction wherever this is likely to be appreciable. Neglect to allow for this has frequently resulted in fracture to flanges or pipes, and explosion has sometimes followed.

Various devices have been introduced from time to time to meet the difficulty. Mechanical joints, in which one pipe slides inside another through a gland or stuffing box, or other arrangements are sometimes adopted, the majority of which are more likely to give trouble than to prevent it.

Probably the simplest and most effective method is to introduce one or more U bends at the point or points of greatest expansion. The bend should preferably be of copper, and should be fixed horizontally, or trouble, should water settle in the pipe, would result.

A system of steam pipes, if properly designed and constructed, should require little or no attention beyond

inspection. Where blowing at the joints frequently occurs it will be found to be due either to bad design or construction in the pipe system or flanges, or to the presence of corrosive matter (which has been carried over with the steam) destroying the packing. Every valve should be provided with a small by-pass in order that the pipe may be warmed slowly and equally throughout before the steam is admitted from the main valve.

Steam Traps.—Even in the best designed steam-pipe systems it is not possible to entirely prevent condensation, and water is a great source of trouble both in the pipes and engines. Where serious inconvenience is experienced with water in the cylinders or steam passages it is sometimes necessary to keep the drains almost always open in order to get rid of it, which, needless to say, means a constant blowing away of live steam and an increased coal bill. To get over this difficulty, and at the same time keep the pipes and cylinders free from water, steam traps are very often used. These are automatic in action and allow the water to be blown off at the proper moment. Unfortunately, they are not always reliable, some of them having a number of moving parts with considerable complication.

One type consists of a closed receiver connected to and situated below the pipe or cylinder to be drained and into which the water runs. In this receiver is a ball or float valve, which is raised as the water accumulates until an outlet valve is opened, when the water is ejected. Many different forms of this trap are in use, but the principle is more or less the same in all.

Another type is known as the expansion trap, for the reason that the valves are operated by the expansion of

some part of the apparatus. Fig. 74 illustrates one form.[1] The tube, C, is connected to the pipe to be drained by the orifice at the top, and through which the water passes; it then flows down the tube past the valves, D D, and through the outlet at the bottom. By turning the screw, A, downwards the straps, B B, are tightened, and consequently press against and close the valves. By properly adjusting the screw a point is found where the valves just remain open *as long as water is in the tube*, but as soon as steam begins to pass the increased temperature causes the tube, C, to elongate, thus tightening the straps, B B, and closing the valves until water begins to accumulate again, when the operation is repeated.

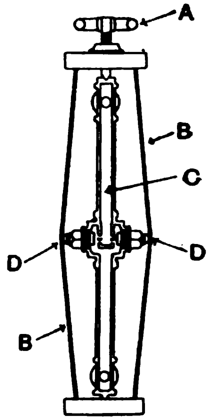

Fig. 74.

Fig. 75 illustrates another trap of the expansion type.[2] The lower or brass pipe is connected to the steam-pipe,

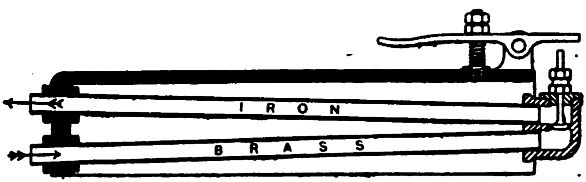

Fig. 75.

the upper iron pipe forming the discharge. These two pipes form the two sides of an isosceles triangle, the valve seat being at the apex. The valve spindle is fixed to the frame of the trap. When cold the brass pipe is contracted,

[1] Royle's patent (Messrs. Haughton & Co., London).
[2] Geipel's patent.

so that the valve is full open, and water is discharged. As soon as steam enters the brass pipe, the latter expands and raises the apex, when the valve is closed. In order that the valve may be set to blow off at any pressure desired, a screw adjustment is provided. When it is desired to blow through, the valve may be opened by hand.

Separators.—Under this head come various appliances for the separation of water both from live and exhaust steam and also for the extraction of oil used in the lubrication of the engine cylinders from the exhaust steam.

The former are frequently known as steam driers, and are used in case of live steam to prevent water getting into the cylinders and valve chest and producing increased condensation and other troubles. These appliances usually take one of two forms.

In one case the particles of water or oil are carried with the steam into a chamber filled with baffle plates which catch the oil or water and causes it to drain away.

In the other case the steam is given a rotatory motion by means of a screw baffle, and the centrifugal force throws the particles of water or oil outward to the sides of the chamber, where it drains off.

Fig. 76 illustrates the second kind, viz. the centrifugal.[1] The figure is self-explanatory. A similar apparatus being used for removing water from live steam, and for removing oil from exhaust steam. In the latter case nearly the whole of the oil used in lubricating the cylinders may be recovered, while with condensing engines, or with feed-water heaters where the exhaust steam mixes with the feed-water, the condensed steam

[1] The Empire Engineering Company, Manchester.

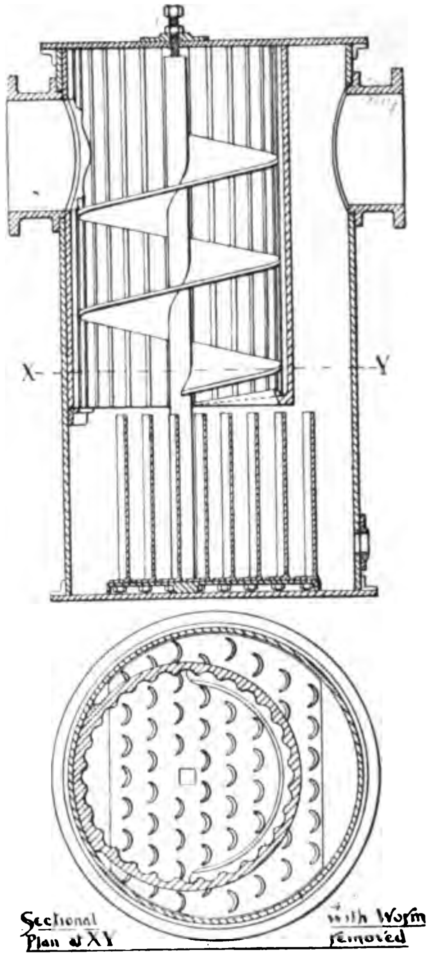

Fig. 76.—Sectional view of "Empire" Patent Oil Separator.

may be utilized without danger to the boiler-tubes and plates.

By the use of a similar appliance the steam from a

non-condensing engine may be carried directly into the stack without danger of injuring the brickwork. A cut of the latter appliance is shown in fig. 77. The exhaust steam enters at E and impinges on the baffle cone B and the other baffles B B B, leaving the particles of water on the baffles to drain away, and passing out at O.

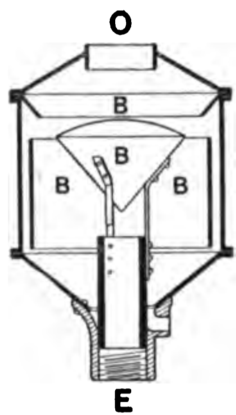

Fig. 77.

Feed-water Pipes.—As one of the chief aims of the electrical engineer is to maintain the continuity of supply of electricity to the consumer, it is curious to note that in some of the older stations, where every provision has been made in the way of duplicate boilers, engines, &c., the steam and feed-water pipes have been so arranged that in the event of an accident to any one section the total disablement of the plant would result.

The duplication or interchangeability of the steam and feed-pipe systems are quite as necessary as the duplication of any other portion of the plant, and it has now become the orthodox thing to put in some arrangement of feed-water pipes which, in the event of accident to some part, does not interfere with the remainder.

Duplicate feed-water pipes are, as a rule, taken from the pumps to the boilers, and arranged either in the form of a ring, similar to the system of steam pipe previously described, or in some other way, so that should one side become disabled, the other could be brought into requisition.

Where the water is very hard[1] some such arrangement is absolutely necessary—unless a water-softening device is provided, and even in the latter case the duplicate feed is certainly advisable, in order that repairs may be effected on any portion of the system.

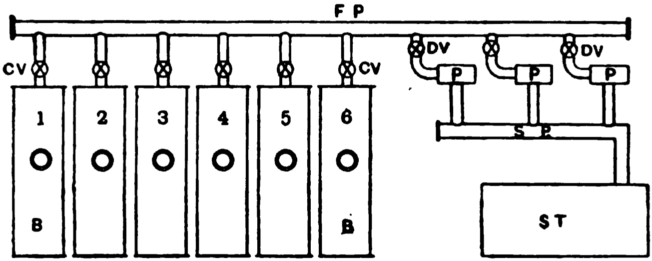

Fig. 78.

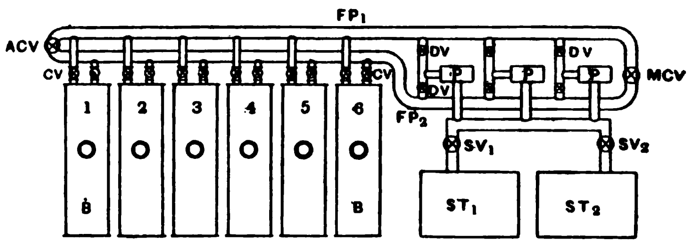

Fig. 79.

S T, storage tank; S V, suction valve; F P, feed pipe; S P, suction pipe; P, pumps; D V, delivery valve; M C V, main circulating valve; A C V, auxiliary valve; C V, check valve; B, boiler.

At the boiler end of the feed service, and just before the feed-water enters the boiler, check valves are fixed. These valves, while freely allowing the passage of water into the boiler, are intended to prevent the back flow of the water from the boiler into the feed pipes should anything go wrong.

Where the supply of water is taken from a company's

[1] See "Hard Feed-water" (p. 216).

service, storage tanks are also usually provided, so that, in the event of the water being shut off from any cause, a supply can be drawn from the tanks for several hours or even two or three days, depending upon their capacity. Sometimes the tanks are duplicated in order to allow of cleaning and repair.

Figs. 78 and 79 illustrate two systems of feed pipes, the former being a single-feed system and the latter a double or ring system.

Feed Pumps.—Pumps or injectors are required to force the feed-water into the boilers against the steam pressure. Various forms are in use, but whatever type is adopted it should be of a thoroughly reliable character and not easily put out of order, as it has to do its work with but little attention from one end of the year to the other. If the feed supply is properly adjusted, as many pumps as are required should be kept continuously working, so that the quantity of water admitted to the boiler is as nearly as possible equal to that which is evaporated, and the level of the water in the boiler is constantly maintained. The position of the pumps is shown at P, figs. 78 and 79. Injectors are sometimes used instead of, or as an auxiliary to, the pumps, and while, as a rule, they are not as reliable as the latter, they form a useful adjunct to the feed system, and possess the advantage of having no moving parts, and consequently require but little repairs.

Coal Saving Devices.—Next to maintaining a continuous supply of electricity to the consumer, the economical working of the station is of the first importance to the engineer, and many devices have been introduced for the purpose of reducing the coal bill, which is usually the heaviest item of expenditure in the production of electricity.

Economizer (see figs. 80 and 81 Green's economizer).—This apparatus has for its object the utilization of the

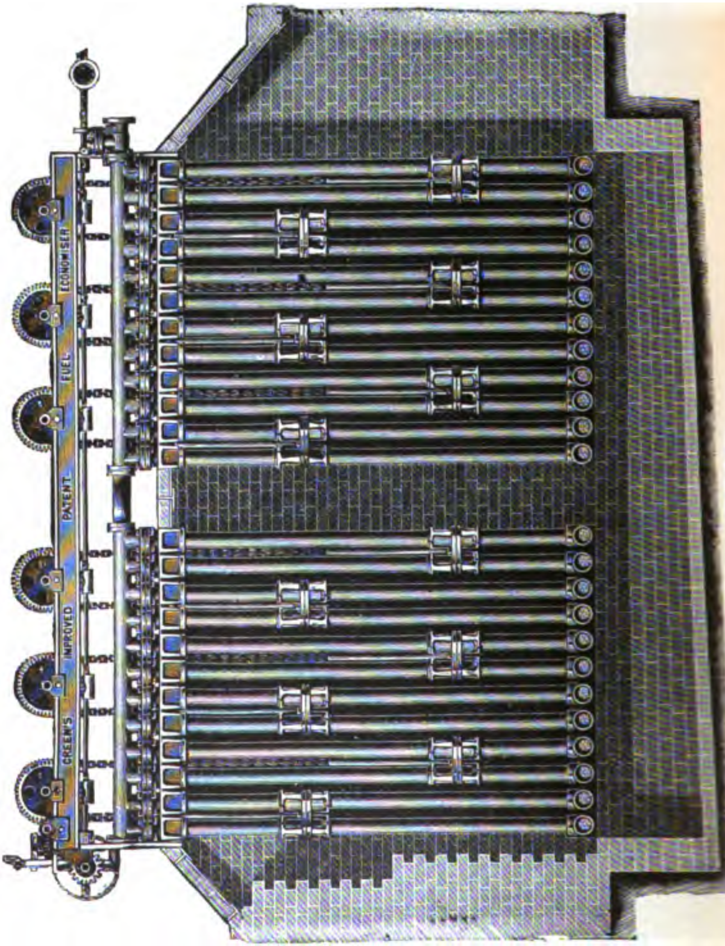

Fig. 80.

waste heat in the boiler flues. It consists of a group or nest of tubes built into an auxiliary flue, and so arranged

that the whole of the gases from the boilers can be made to pass around them. The feed-water flows through the tubes before entering the boilers, and its temperature is raised to a degree dependent upon the temperature of the

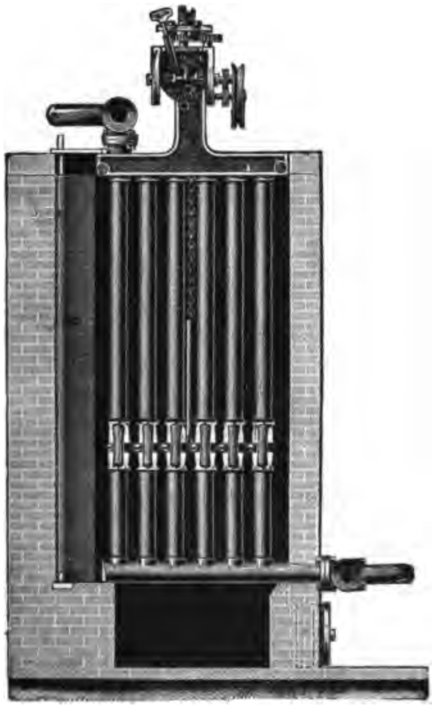

Fig. 81.

gases and the efficiency of the apparatus. When hard water[1] is used the efficiency falls rapidly, as scale is formed on the tubes. Deposits of soot on the outside would also affect the temperature materially, but this is

[1] See "Hard Feed-water" (p. 216).

removed by scrapers, which are kept moving up and down the tubes. Unfortunately, economizers require considerable floor space, and are sometimes omitted from central stations in consequence.

Water Heaters.[1]—These appliances are designed with a view to heating the feed-water by means of the exhaust steam. Although they are made in a number of different forms, the principle is more or less the same in all. A nest of tubes, through which the exhaust steam passes is enclosed in an outer shell. Surrounding the tubes and inside the shell, the feed-water rises on its way to the boilers, and as the tubes are heated by the exhaust steam the temperature of the water is raised. The deposit of scale on the tubes, due to hard water, has the effect of reducing the efficiency of this apparatus, as in the case of the economizer, and frequent blowing out of the mud or cleaning is necessary in both cases.

When the feed-water is very hard it is advisable that a pressure gauge and a dead-weight relief valve be inserted in the feed-water pipe between the pumps and the heaters or economizers, as not unfrequently the pipes become choked with deposit, and a careless stoker, finding the feed-water not entering the boilers fast enough, would probably fracture the tubes by increasing the speed of the pumps, and so obtaining excessive pressure. Thermometers placed in the delivery pipes from the heaters and economizers are also useful, as they show at once whether the apparatus is doing its work properly or not.

Automatic Stokers.—The efficiency of a boiler is greatly affected by the manner in which it is fired, and it was with the object of increasing the efficiency and at the

[1] See the Warwick Heater detartarizer (p. 219).

same time reducing labour that automatic stokers were introduced.

The principle of all these appliances is the same, and consists of feeding the furnace continuously with small quantities of fuel, instead of overloading it and so allowing a large proportion of the combustible gases to pass into the flues unburnt.

Automatic stokers are of two kinds, viz. "coking" and "sprinkling."

In both kinds small coal is thrown into a "hopper," or conveyed thither by means of a mechanical conveyer.

In case of the coking stoker it is then automatically dropped in small quantities at a time on to the "dead plate" immediately inside the fire door; here the gases, on being liberated, pass over the clear fire beyond and are consumed, while the remaining coke is pushed forward by means of an automatic ram.

The "sprinkling" stoker works somewhat differently, the coal being jerked by means of springs into the furnace direct.

The fire bars are kept moving by means of mechanism in order to prevent clinkers adhering to them.

An additional fire door, to permit of hand firing if found necessary, is usually provided.

Like the majority of automatic appliances, however, mechanical stokers are liable to give trouble, chiefly on account of the large amount of gear required, which is liable to considerable wear and tear and consequent breakdown. On the coal fields, where fuel may be obtained practically at the pit's mouth, the cost of repairs and maintenance may not be a serious item when the fuel economy is considered, but in London, where half the total cost of the coal delivered is represented by railway

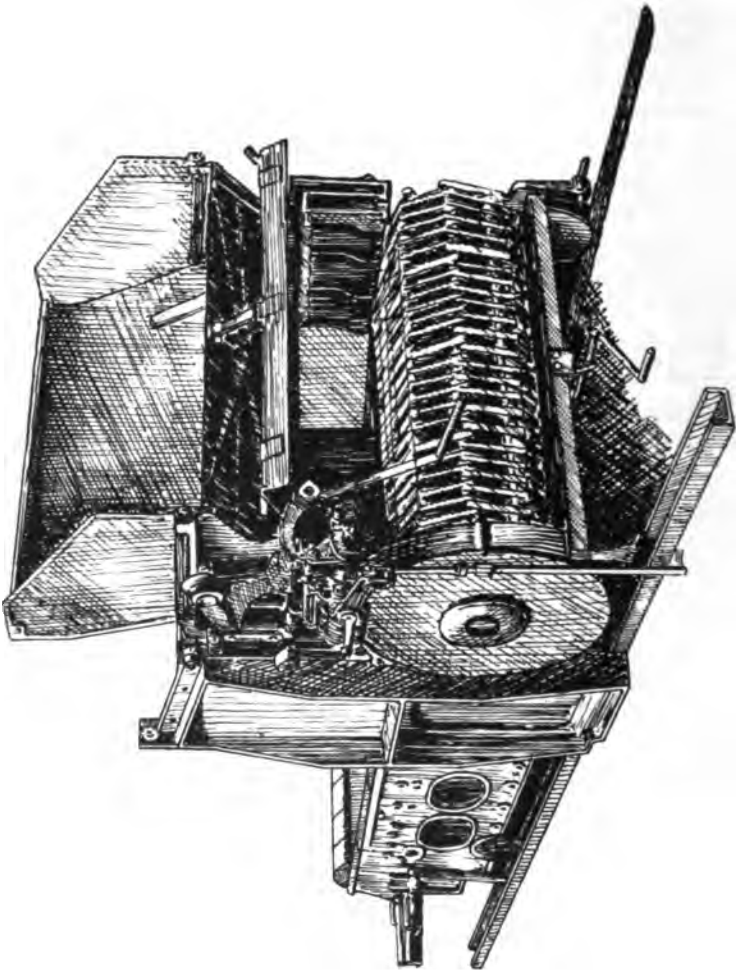

Fig. 82.

carriage, it is a very different matter. One of the authors made careful inquiries of all the chief engineers

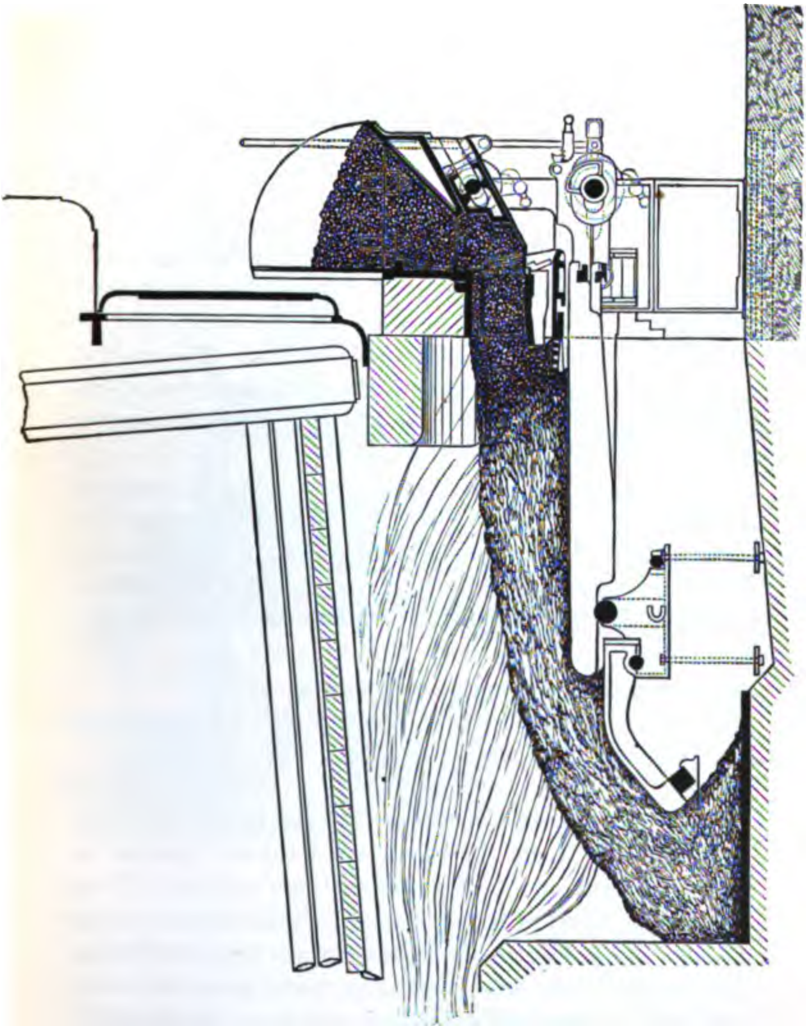

Fig. 83.

of central stations in London, and found the general opinion was not very favourable to mechanical stokers,

chiefly on account of the cost of repairs and unreliability.[1]

Two illustrations of top-feed coking stokers are shown in figs. 82 and 83, the first being a Babcock chain grate and the second being a longitudinal section of a Vicars stoker.

Under-feed Stokers.—A type of stoker differing from the others, and which, though old in principle, has only recently been re-introduced, is known as the under-feed. In this case the fuel is fed below the fire and forced up through it by means of a screw or ram. The makers claim an absolutely smokeless furnace and very complete combustion, while the working parts are fewer in number than many stokers of the top-feed type.

A section of one form of under-feed stoker is shown in fig. 84.

Lagging.—The waste due to radiation from the boilers and steam plant would be very high indeed if the surfaces were left exposed to the air, and it is therefore usual to cover them with some non-conducting composition which materially reduces the loss. The shells of the boilers or the top of the overtop chamber, the cylinders of the engines, and the steam pipes are invariably so covered.

The flanges of steam pipes are frequently left uncovered to enable the joints to be attended to, and this is responsible for more loss than is sometimes realized. There are several forms of removable or portable lagging on the market, most of which are suitable for covering the flanges, and at the same time rendering them accessible when required. When feed-water heaters are used it is desirable

[1] See "Stokers for Electricity Generating Stations," a paper read before the Society of Engineers on November 30th, 1903.

that the exhaust pipes should be covered as well as the hot-water section of the feed-water pipes.

Superheating.—Even with the best designed steam-pipe systems and most efficient lagging condensation is continually taking place, as well as in the steam chests, cylinders, and steam passages of the engines, and where

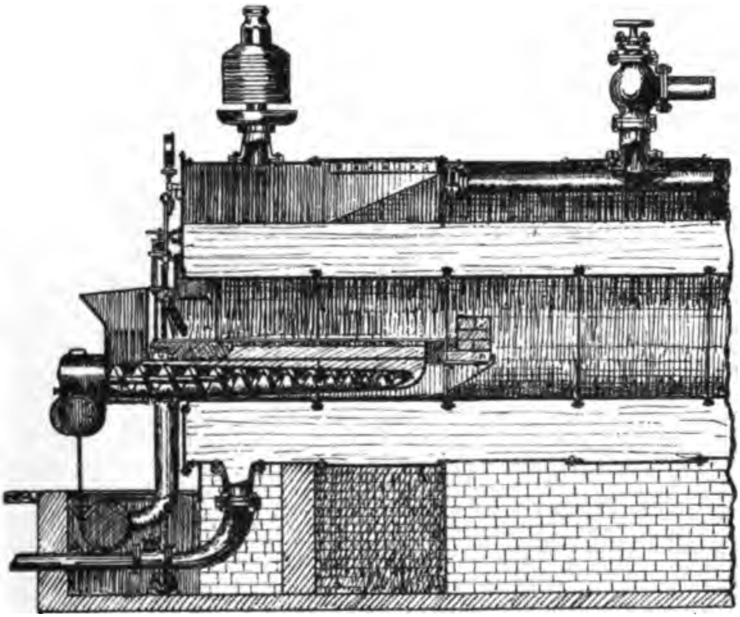

Fig. 84.

steam pipes are large in diameter, of considerable length, and imperfectly covered, the loss in the whole system may amount to 30 per cent. or more.

Superheating the steam would considerably reduce this loss, but until recently very little has been done in this direction, as the risk attendant upon the operation—

unless the appliances are very carefully designed and subjected to careful and intelligent usage—is considerable. When steam is superheated it is raised to a higher temperature than that at which it leaves the boiler at a given pressure, and would consequently tend to evaporate any

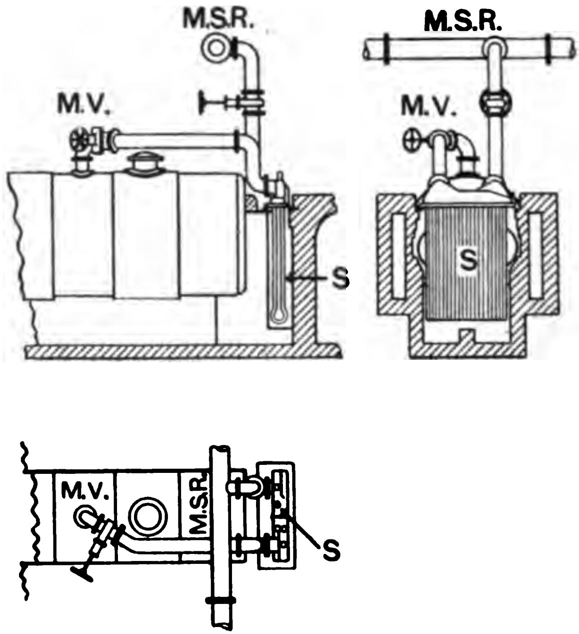

Fig. 85.

water which may be present in the steam pipes and passages. Fall of temperature due to radiation would also have to be very appreciable before condensation would begin.

Recently several superheaters have been put on the market which bid fair to be successful. Each consists of

a series of pipes placed in the boiler flue, or—as in case of water-tube boilers—directly beneath the steam drum, where the temperature is much higher than the steam. Through these pipes the steam passes on its way to the engines, and its temperature is consequently raised.

Superheaters.—The accompanying fig. (no. 85) shows one form of superheater adapted to a Lancashire boiler. The

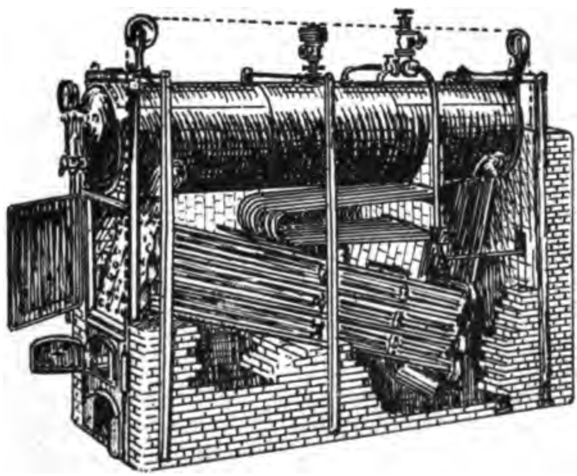

Fig. 86.

steam leaves the boiler at the main valve, M V, and passes along the steam pipe to one side of the row of bent tubes, S, which form the superheater, and which is suspended in the flue. Here the temperature of the steam is raised by the heat from the flue gases, and passes from the other side of the superheater to the main steam range, M S R.

A Babcock superheater attached to a water-tube boiler is shown in fig. 86.

Condensing.—Where a large quantity of water is available which has not to be paid for, one of the best means of reducing the coal bill is by using condensing engines. As a rule, unfortunately, water is expensive, especially in London, and this usually precludes their general adoption. The subject is more fully dealt with under the head of "Engines."

Hard Feed-water.—We have already referred to the loss as well as the danger due to the formation of scale in the boilers consequent upon the use of "hard" water. Unfortunately, in many districts, including London, soft water is not available, and endless trouble is the result, to say nothing of the cost of cleaning the boilers frequently, which means a considerable inflation of the wages bill.

Hard water contains in solution the carbonates and sulphates of calcium and magnesium, besides other salts, as well as matter in suspension. The water supplied by the London companies frequently contains twenty-four grains or more of solid matter per gallon. As soon as the water boils the carbonic acid in solution is given off, causing precipitation of the carbonates, while the sulphates are rendered insoluble, and are also precipitated. The precipitated matter is then deposited on the tubes and plates, and forms into a hard scale, which, being a very bad conductor of heat, greatly reduces the efficiency of the boiler, and is liable to produce over-heating and rupture.

It has been estimated that one-sixteenth of an inch of average scale will reduce the evaporative efficiency of the boiler by 10 per cent. The scale is also formed on the feed inlet pipes and feed valves, as well as on the tubes of the feed-water heaters and economizers, the efficiency of which is thereby greatly decreased.

One of two methods is usually adopted with a view to minimizing the formation of scale, the absolute prevention being practically impossible except by distillation. The first method is that of treating the water before it enters the boiler, and, if successful, is by far the best, as it protects the heaters, economizers, and feed pipes, as well as the boiler. The other method consists of treating the water in the boiler, and in this case the feed pipes, &c., are not protected. Water softening consists in adding to the water certain chemical reagents in proper proportions, and producing precipitation, after which the water is passed through a filter and the solid matter left behind. When bicarbonates of calcium and magnesium are present the addition of lime to the water will cause precipitation, but it will not affect the sulphates, and the addition of soda is then necessary.

Water softeners are simply appliances for treating water more or less automatically, but as it is necessary that the quantity of water treated per hour should be constant, if the best results are to be obtained, it is usual to run the water after treatment into one or more large storage tanks. This is also desirable, as the filter does not always completely remove the precipitated matter, and settlement continues in the tanks.

The majority of water-softening appliances depend for the precipitation of the solid matter upon reagents, and both the chemicals and the water are generally used cold, the result being that as soon as the latter reaches the boiler and rises in temperature to the boiling point further precipitation takes place, and scale is formed on the plates and tubes. With a view to removing this difficulty and to further purify the feed-water, appliances have been introduced in which the feed-water is raised to a high

temperature and simultaneously mixed with a proper proportion of reagent.

A diagrammatic section of one form of this type of heater, known as the "Warwick Detartarizer," is shown below (fig. 87). Its action is as follows:—The feed-water entering at A mixes with the reagent which enters at B, and then streams in the form of spray through the holes and over the sides of the trays, as shown. The exhaust steam after passing through the oil separator meets the water and gives up its heat. The water now passes down through the tube, C, to the bottom of the large settling-tank, where the lime, salts, &c., are deposited, and, rising again to the top of the tank, passes down the second tube, D, to the filter chamber, where any remaining oil not removed by the separator, and by admixture with the soda solution and the lime particles has now become a flaky compound, is caught together with any solid matter which may have been carried over, and the pure water then passes from the filter to the pumps. The head of water in the heater removes the difficulty which would otherwise be experienced in pumping hot water. It will be seen, therefore, that this apparatus serves the double purpose of heating and softening the feed water.

The second method referred to is frequently adopted, and numerous boiler compositions are on sale, which the makers claim will prevent the formation of scale by keeping the deposit in the form of mud that can be washed out when the boiler is opened. Probably a large proportion of these compositions do more harm than good, corroding the plates, and destroying the joints of the valves and fittings, and sometimes causing serious leakage. If priming takes place, the composition is carried over into the steam pipes and possibly into the engines, pro-

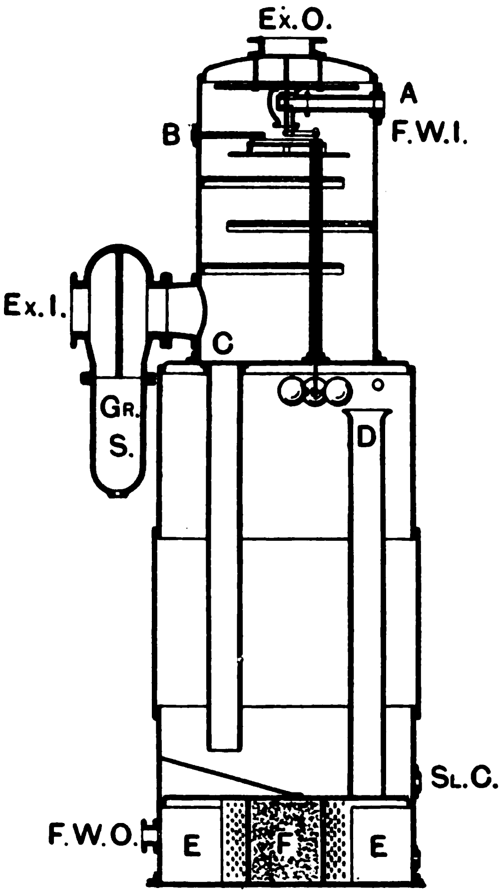

Fig. 87.

ducing disastrous results upon all the joints and corroding the valve faces. The deposit can, to a certain extent, be removed before it is hardened into scale by "blowing

down" the water and lowering it, say, half an inch in the gauge glasses once every day.

Smoke Consumers, as they are misnamed, are appliances fitted to boilers with a view to preventing smoke issuing from the stack. If bituminous coal is used this trouble in London becomes serious; hence the reason that "smokeless" coal is generally utilized. It is well known that when adding fresh fuel to the furnace a rapid evolution of gas and smoke takes place which requires additional oxygen for its combustion. The fire door is sometimes perforated in order to admit more air during this period, and for a short time after, until the fire becomes clear, the volume of air being regulated by means of a moveable ventilator. The admission of cold air, however, whether through a ventilator or by opening the fire door, is inadvisable, and may cause serious chilling of the tubes and plates. In order to overcome this difficulty the air, before being admitted, is sometimes heated by admixture with a jet of live steam, or by passing through a heating arrangement just inside the furnace door. The accompanying illustration (fig. 88) shows the former plan. Under-feed stokers should also answer the purpose of preventing smoke. (See AUTOMATIC STOKERS).

Calorimeter.—The importance of knowing the calorific value of the coal used should not be overlooked, as different deliveries from the same colliery and even from the same seam may vary considerably; some station engineers decline to place contracts for coal except upon a minimum calorific guarantee. Frequent tests can be made and a mean taken, which, if the contract so provides, can be used as a basis in making up the account. For the purpose of determining the calorific value an instrument known as a Calorimeter is used. The principle

adopted is that of the combustion of a given quantity of fuel (with an oxygen mixture) while immersed in a given quantity of water, the resultant increase in temperature of the liquid being the factor upon which the calculation is made.[1]

CO_2 Recorder.—In order to obtain the maximum calorific value from coal perfect combustion is necessary,

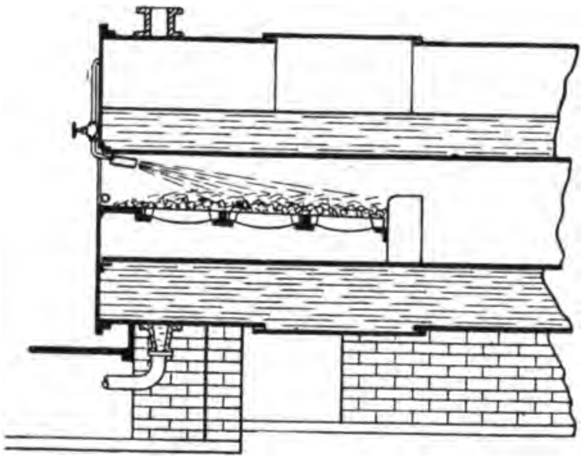

Fig. 88.

and this is not possible in any ordinary boiler. Careless stoking, however, may increase the coal bill 50 per cent. In order to obtain the best results the proper regulation of the draught in order that the right proportion of air is admitted is essential, and although the theoretical quantity is given in many text-books, it is found in practice that it has to be exceeded to about the extent of one-third. Less

[1] See a small pamphlet published by Alexander Wright & Co. makers of the Thompson Calorimeter, 55 and 56, Millbank Street, S.W.

than this is insufficient, and results in very imperfect combustion, and an excess is not only useless but wasteful, as it tends to cool the boiler. Combustion of hydro-carbon results in the formation of carbonic dioxide gas, or CO_2, and the more perfect the combustion the higher the percentage of CO_2 in the flue gases until the theoretical maximum of 21 per cent. is reached.

It is found that if the proportion of CO_2 falls, to, say, 2 per cent. the loss in fuel is 90 per cent., while if it is 15 per cent. the loss is only 12 per cent.

The CO_2 recorder is an instrument for continuously recording the percentage of CO_2 in the flues of the boilers and so keeping a constant check upon the stokers.[1]

Circulators.—In order to obtain more perfect circulation in boilers (more especially those of the shell type) with the object of securing greater evaporative efficiency and avoiding unequal stress in the plates and stays, appliances known as circulators have been introduced with good results. These circulators are usually in the form of cowls attached to the top and bottom of the Galloway or cross-tubes as shown in fig. 90. The plate is self-explanatory, the water rising in the cross-tubes draws up that from the lower part of the boiler and projects it toward the front or in any other direction desired. These appliances can be attached to any boiler of the cross-tube type without drilling or interfering with the shell or tubes in any way. The same plate shows a "deflector," which is placed in the flue some distance behind the bridge, the

[1] The "Ados," manufactured by Sanders, Rehders & Co., 108, Fenchurch Street, E.C., and the "Krell" by the Smoke Preventer Company, Blackburn.

[2] Invented by H. Schofield, of Circulators, Ltd., 147, Leadenhall Street, E.C.

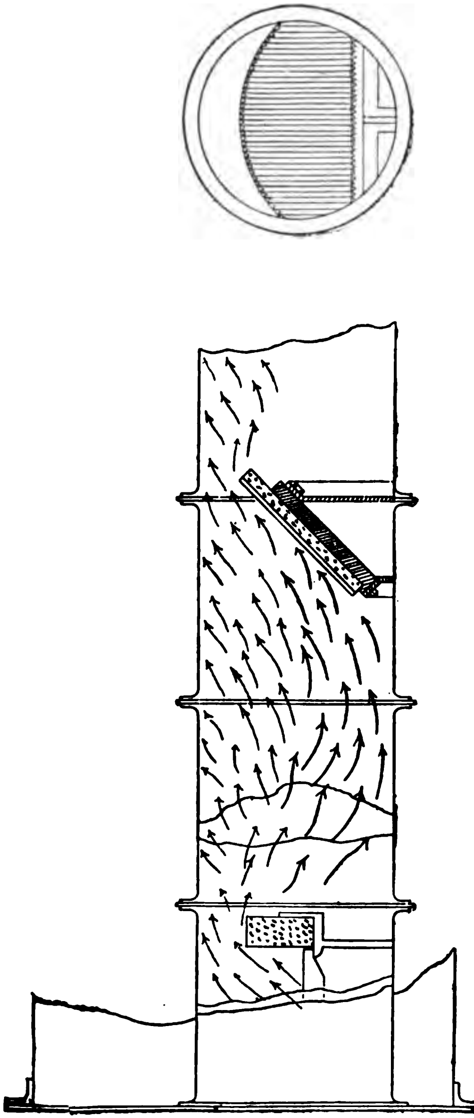

Fig. 89.

intervening space acting as a second combustion chamber.[1] Fig. 89 shows it on a larger scale.

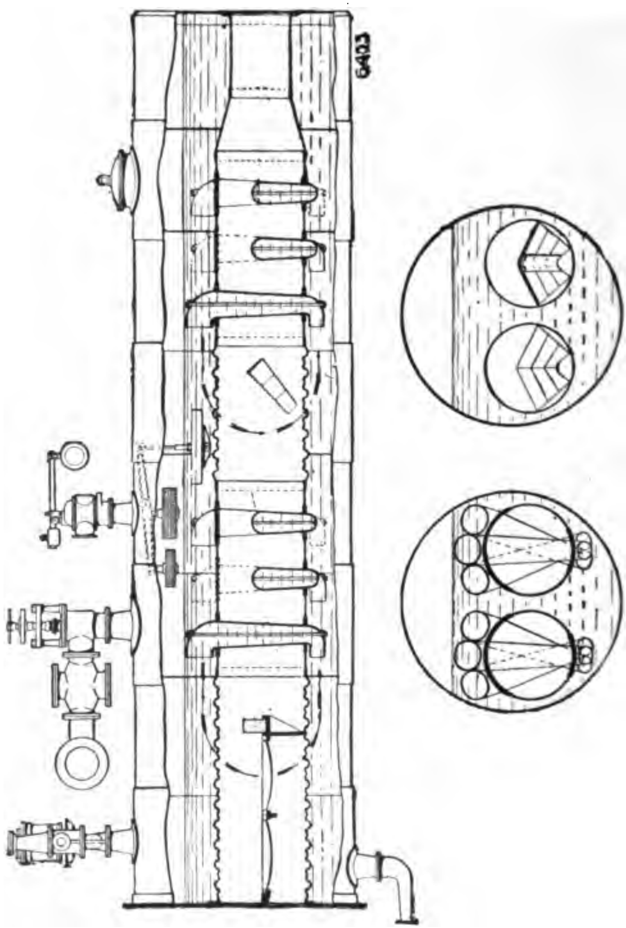

Fig. 90

[1] Invented by H. Schofield, of Circulators, Ltd., 147, Leadenhall Street, E.C.

PRIME MOVERS.

Steam Engines.—Since the days of the low-pressure single-cylinder type of engine great improvements have been effected, both in the construction and efficiency of the steam engine, the latter being due chiefly to the use of high-pressure steam, multiple expansion and condensing. When electric lighting was first introduced, mechanical engineers, who prided themselves upon the excellence of their engines, very soon found that important improvements and modifications would be necessary in order to meet its requirements, and, although they were loth to admit obvious defects, a change for the better was soon apparent. It was a continual fight in those days to try and convince the mechanical engineer that shutting down, while electricity was being supplied, because he wanted to take up a bearing or to effect some repairs to the engine, could not be tolerated. The consumption of steam was also a bone of contention, and the electrical engineer usually objected to the erratic behaviour of that part of the apparatus which was *called* a governor.

Improvements in valves and valve gear, adjustable bearings, anti-friction metal, improved lubricants and methods of lubrication, more perfect workmanship, as well as materials of a higher quality, have all helped to make the steam engine far more reliable than it used to be, and without doubt most first-class engines could now be depended upon to run continuously for months if required, while the governing is in many cases excellent.

Types of Engines.—To describe all the different forms of engines in use in central stations would require a

volume to itself, and it is proposed therefore to deal only with those which illustrate types, or which possess features of special interest. Reciprocating engines may be divided into two general classes, viz. (*a*) Single-acting, and (*b*) double-acting. These may again be subdivided into numerous others.

(*a*) A single-acting engine is one in which the steam operates on one side of the pistons only. It is usually made with two or three cylinders, the cranks being arranged so that two or three separate impulses are given per revolution. It runs at a high speed, is usually vertical (i.e. the cylinders are fixed vertically above the shaft), compound, or triple-expansion, and may be either condensing or non-condensing.

(*b*) In a double-acting engine the steam operates on both sides of the piston alternately. It is made to run both at high and low speed, may be either vertical or horizontal, compound or triple-expansion, condensing or non-condensing.

In compound or triple-expansion single-acting engines the cylinders are invariably arranged "tandem," i.e. end to end, while double-acting engines are more frequently made with the cylinders side by side, although both methods are adopted, particularly with horizontal engines.

The continuity of the supply depends as much upon the engine as upon any part of the generating plant, while the cost of production is largely regulated by it. In its selection, therefore, the following points are worthy of consideration:—

Efficiency.—By this is meant the all-round efficiency under normal working conditions. An engine may show abnormally good results during an official test with everything in its favour, but as it is improbable that these

conditions can be maintained in the works, such results are of little value. If a non-condensing engine of, say, 200 or 300 i.h.-p., did not require more than 20 to 22 lbs. of steam per i.h.-p. at its best load, most engineers would consider it efficient, and it is probable that, in order to maintain this efficiency, the friction factor of the engine would have to be low and the valves kept carefully adjusted.

Durability.—Solidity in the general construction is essential. The crank-shaft, and all the most important of the reciprocating parts, should be of high quality mild steel, of solid construction and good workmanship, and having a very high factor of safety. The bed-plate and frame should be massive, and when securely bolted down the engine should be free from excessive vibration.

Accessibility.—All the working parts should be readily accessible, both for examination and repairs, and it is a distinct advantage when every part (with the exception of the valves and pistons, of course) can be examined while running. The main bearings should be so constructed that all the brasses can be removed without dismantling the engine, and they should be adjustable from the outside.

Simplicity.—Excessive complication in the working parts should be avoided, and the fewer the pieces the better, as every additional eccentric, lever, &c., requires additional attention and increases the risk, while, in the event of repairs being necessary, the engine takes longer to dismantle and put together again.

Reliability.—General reliability is essential, and, as before stated, a first-class engine should be capable of running continuously for months if necessary. Hot bearings should be unknown except under abnormal cir-

cumstances, and the lubrication should be as perfect as possible.[1]

Renewals.—All working parts should be made strictly to gauge and interchangeable, so that any part may be replaced in a very short time, and spare brasses, valves, &c., should be kept for emergencies.[2]

Steadiness.—Steady running is essential, and the turning moment should therefore be even throughout the stroke. There should be no excessive vibration or noise, and the governing should be as nearly perfect as possible.

As a general rule engines used in central stations are either of the high-speed vertical type or the low-speed horizontal type, although latterly vertical marine-type engines of moderate speed, from 150 to 200 revolutions per minute, seem to be coming into favour. (See Fig. 91.)

High-speed Vertical.—Makers of this type of engine, which usually runs at from 200 to 500 revolutions per minute, claim that the following advantages are obtained by its use over the low-speed type:—

1. It runs at a high speed, and consequently for a given power is smaller and lighter than a low-speed engine.

2. The turning moment is more even in consequence of the much greater number of impulses per minute, and the periodic variations in speed, though more frequent, are smaller in magnitude.

3. The loss by initial condensation is reduced by shorter exposure of the cylinder surfaces to successive changes of temperature.

4. Where high-speed dynamos are used the engine can

[1] See Chapter VIII., Bearings and lubrication (Dynamos).

[2] See Chapter VIII., Repairs and renewals (Dynamos).

be coupled direct, thus saving the loss in transmission due to the use of belting or ropes.

5. It takes up very little floor space as compared with the low-speed engine.

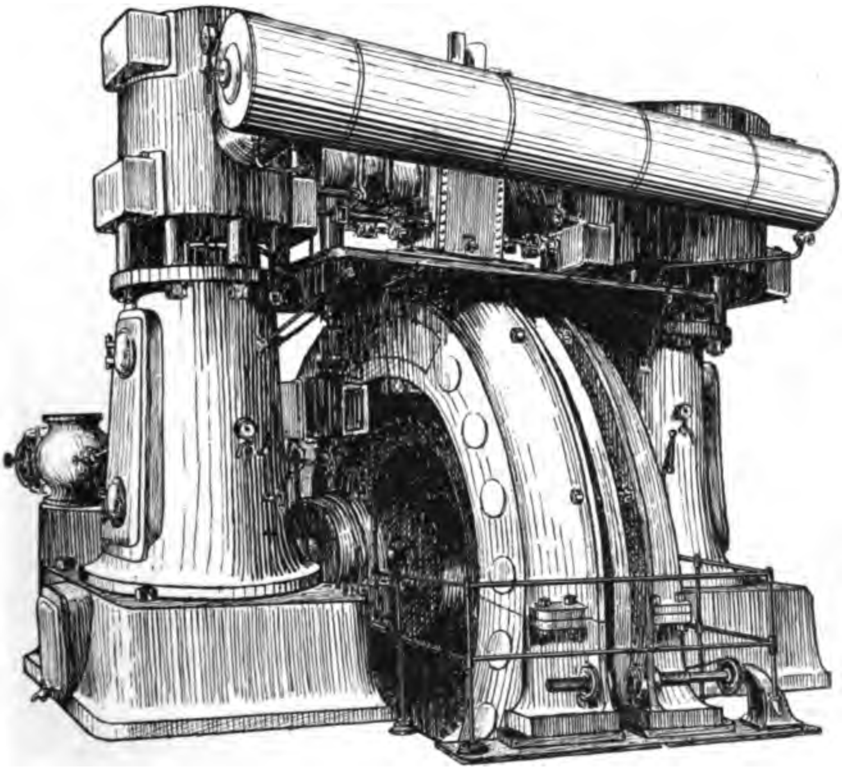

Fig. 91.

6. In case of repairs, all the parts, being light, are easily handled.

Makers of low-speed engines reply to these statements as follows:—

1. As it runs at a high speed and is so small and light, it is far more liable to break down, and is less durable. This is proved by the fact that, while broken crank-shafts and other parts are of frequent occurrence with high-speed engines, such accidents are very rare with the low-speed type, and that when litigation or other trouble, consequent upon vibration, has resulted, it has been almost invariably due to high-speed engines.

2. That the turning moment is *not as even* is proved by the trouble experienced in running alternators in parallel with high-speed engines, while with low-speed plant there is no difficulty.

3. That the efficiency of a good low-speed engine is at least equal to that of a high-speed, *under normal working conditions*, and that, therefore, the claim is valueless.

4. That high-speed dynamos are not essential.

5. That low-speed engines being more reliable, it is better to sacrifice the floor space.

6. That all modern central stations have overhead cranes, and that repairs are rarely needed with low-speed plant.

It will be seen that opinions differ in the case of engines, as in nearly all other matters, and these differences of opinion are shared by engineers of stations as well as makers.

Even amongst makers and users of high-speed engines opinions are divided respecting the relative merits and demerits of the single-acting and double-acting engine. Those who prefer the former claim that as they are in constant thrust the working parts are always in compression, enabling a high speed to be obtained without knocking, thus obviating the necessity of frequently

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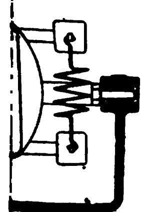

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setting up the brasses, and also reducing the wear and tear and noise.

Votaries of the double-acting engine reply that, as the working parts of the single-acting engine are always in compression, and the strain therefore, always in one direction, there is no opportunity for a film of oil to form between the bearing surfaces, and the wear and tear is, therefore, much greater ![1]

Willans's Central-valve Engine.[2]—This engine, which is illustrated in fig. 92, is largely used for central station work. As will be seen, it is of the single-acting variety. The drawing shows a compound two-crank engine in sectional elevation. The cylinders are arranged tandem, the pistons being coupled together with the hollow piston-rod, P R, and inside of which the valves work—independent motion being imparted to them by means of an eccentric on the crank, as shown. The distribution of the steam is briefly as follows:—

Entering at the steam inlet, S I, it passes through the throttle valve, T V, into the steam chest, S C, thence through ports 1 1 (see left half), by way of the hollow piston-rod, P R, and ports 2 2, into the high-pressure cylinder, H P. The piston now moves downward, the ports 1 1 being closed to the steam chest by the gland G_1, thus cutting off the steam. When the piston is nearly at the bottom of the stroke, the valve V_1 has risen above the ports 2 2, thus connecting them with ports 3 3, and the steam passes through them into the receiver, R. Practically the same cycle occurs in the low-pressure cylinder, and as the two operations occur simultaneously we must return to the beginning of the stroke in order to follow

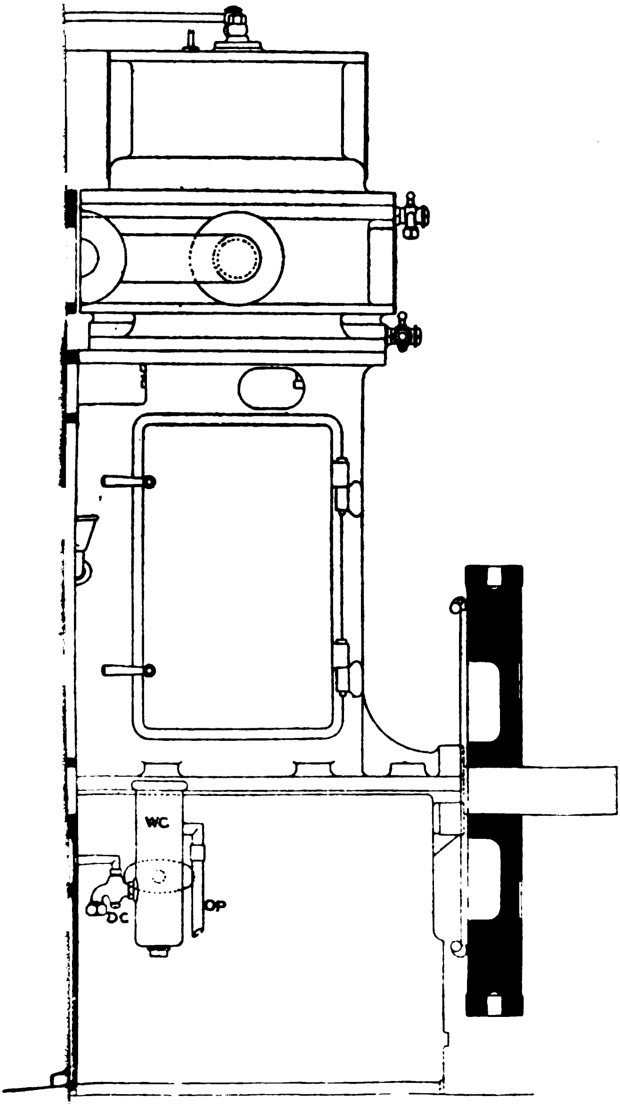
[1] See p. 236. [2] Makers, Messrs. Willans & Robinson.

it. Ports 4 4 and 5 5 are now open to the receiver, R, and the steam (which passes into R from previous stroke) passes into the low-pressure cylinder, L P, and the piston descends, closing ports 4 4 by means of the gland G_2. When nearly at the bottom of the stroke, valve V_2 rises above ports 5 5, connecting them with ports 6 6, and allowing the steam to pass into the exhaust chamber and thence to the exhaust pipe. The cut-off is decided by the depth of the gland and the insertion of a packing piece, as shown. The engine is completely closed in, and the crank-shaft and eccentrics run in a bath of oil. The guide piston, G P, also acts as an air buffer, and on the up-stroke compresses the air in the chamber above, thus keeping the brasses on the crank in compression. The speed is governed by means of a governor on the flywheel, which is connected by means of a rod to the throttle valve, T V.

Scott Engine.[1]—This engine, like the Willans, is entirely enclosed, as far as the reciprocating parts are concerned, thus preventing the waste of oil due to splashing. Fig. 94 shows a sectional front elevation of one half of a two-crank engine, the other half showing the outer casing. Fig. 93 is a sectional side elevation of the same.

There is only one cylinder to each crank, each cylinder being independent of the other as regards the steam distribution, although both are controlled by the same governor. The ring-shaped piston P P, works in the annular space, A A, which is formed by the outer shell of the cylinder and the liner, L L. Two piston-rods, P R, pass through glands at the bottom of the cylinder, and are connected together at the lower end by means of a cross-

[1] Reavel & Co., Ipswich.



ig. 94.

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piece or gudgeon, T. The compound connecting-rod works on brasses on the gudgeon, and also on the crank-pin. Around the cylinder, A, is the jacket, B, which is connected with the space, J, above the cylinder, and forms with it the steam chest. The two cylindrical valves work inside the liner, the steam admission valve, X, being at the top above the diaphragm, K, the transfer and exhaust valve, L, being below. Both valves are driven by the valve-rod from the bell crank, M.

The steam is distributed through the engine as follows:—

Entering at the admission, V, it passes at once into the jacket, B, surrounding the cylinder, and thence into the space, C, above the cylinder and over the top of and into the admission valve, X, then passing through the spiral-shaped slots or ports (which are of the same shape and dimensions in both valve and liner), into the clearance space, Y, above the piston. The piston moves downwards and also the valves, cutting off the steam. After the point of cut-off has been reached, the steam expands above the piston during the remainder of the down-stroke, at the end of which the transfer valve, L, has just uncovered the transfer ports in the liner. At the same time the exhaust ports, E F, at the bottom of the cylinder are also uncovered by the lower portion of the valve. The spaces above and below the piston are thus connected, and as these spaces are of the same volume the steam is transferred from the upper to the lower side of the piston during the up-stroke without any change of volume, and therefore without change of temperature. After passing half-stroke, the piston covers the transfer ports, and the transfer valve covers the exhaust ports, thus stopping any further passage of steam to below the piston. The steam

which has passed over from above to below the piston now expands, as the piston rises, while that remaining above is compressed into the clearance space, the area of which is such that the steam is raised to its initial temperature and pressure at each stroke. At the commencement of the next stroke the steam below the piston is allowed to exhaust through the passage below the liner, while the new steam which is admitted is only required to fill the cylinder above the piston up to the point of cut-off, the clearance space being already occupied with the compressed steam from the last stroke. The new steam admitted is, therefore, equal only to that transferred to the underside of the piston by the transfer valve during the previous up-stroke.

The admission valve, J, is arranged to act as an automatic cut-off valve. This is effected by the ports X X being cut at an angle both in the liner and valve (see side elevation).

The valve is moved on its axis by the governor on the flywheel, which is connected to the valves by the governor-rod, and the valve connecting-rod. The crank runs in an oil-water bath, formed in the bed-plate.

Although the parts are in compression at all times, as in the case of the Willans engine, it is to a certain extent double-acting, and although it has only one cylinder to each crank they are each compound, the steam expanding below the piston, as described, after having done its work above.

Belliss Engine.[1]—This engine, which is illustrated in fig. 95, is of the double-acting type. The illustration shows a sectional elevation of the low-pressure side and

[1] Messrs. G. E. Belliss & Co., Birmingham.

the valves, as well as the ports and steam-passages of the high-pressure cylinder, while the high-pressure side and part of the cylinder is covered, showing the outer casing. It is a compound engine, but unlike the Willans the cylinders are arranged side by side instead of one above

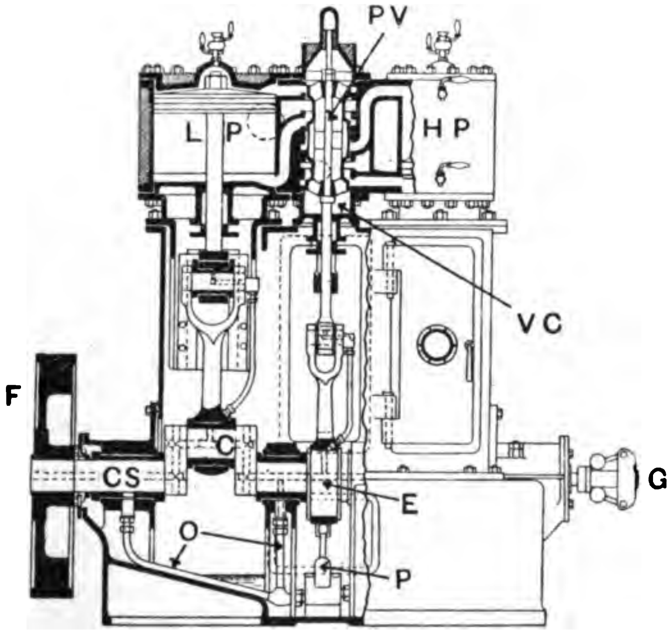


Fig. 95.

the other, and each piston is connected to a separate crank. The steam is distributed by means of a piston-valve driven by a single eccentric situated between the cranks. P V is the piston-valve, which works in the valve chest, V C, from the eccentric, E. At the lower part of the eccentric is the oil-pump, P, which forces oil along the oil-tubes, O, to the hollow crank-shaft, C S, and the cranks,

C. L P is the low-pressure cylinder, the piston being at the top of the stroke; H P is the casing of the high-pressure cylinder, the engine in working being entirely inclosed. The governor, G, is situated at the opposite end of the shaft to the flywheel, F, and controls the cut-off by varying the position of the eccentric. The advantages claimed for the double-acting engine over the single-acting, in addition to that previously mentioned,[1] are as follows:—

Quiet running.—They run much more quietly. Single-acting engines are frequently noisy at light loads, even when cushioning devices are used, consequent upon the momentum of the working parts (which are necessarily heavier than with a double-acting engine) overcoming the steam pressure and throwing the rods temporarily into tension, causing heavy knocking and risk of fracture.

Steady running.—As the number of impulses are for a given speed twice as many as in the single-acting engine,[2] it necessarily follows that if the valves are properly adjusted the turning moment must be more even. Fig. 96 is a sectional elevation of a triple expansion Belliss engine of their latest type.

Rotatory Engines.—A rotatory engine is one in which circular motion is produced directly by the steam without the intervention of reciprocating parts. Numerous forms have been invented, but only one has, we believe, been extensively used in central stations, viz., the Parsons steam turbine.[3] This turbine runs at a speed of one thousand revolutions per minute and upwards depending

[1] See p. 231.

[2] This is only true when the number of cranks is the same in both classes of engine.

[3] Other types are Brush, Westinghouse, Curtis, &c.

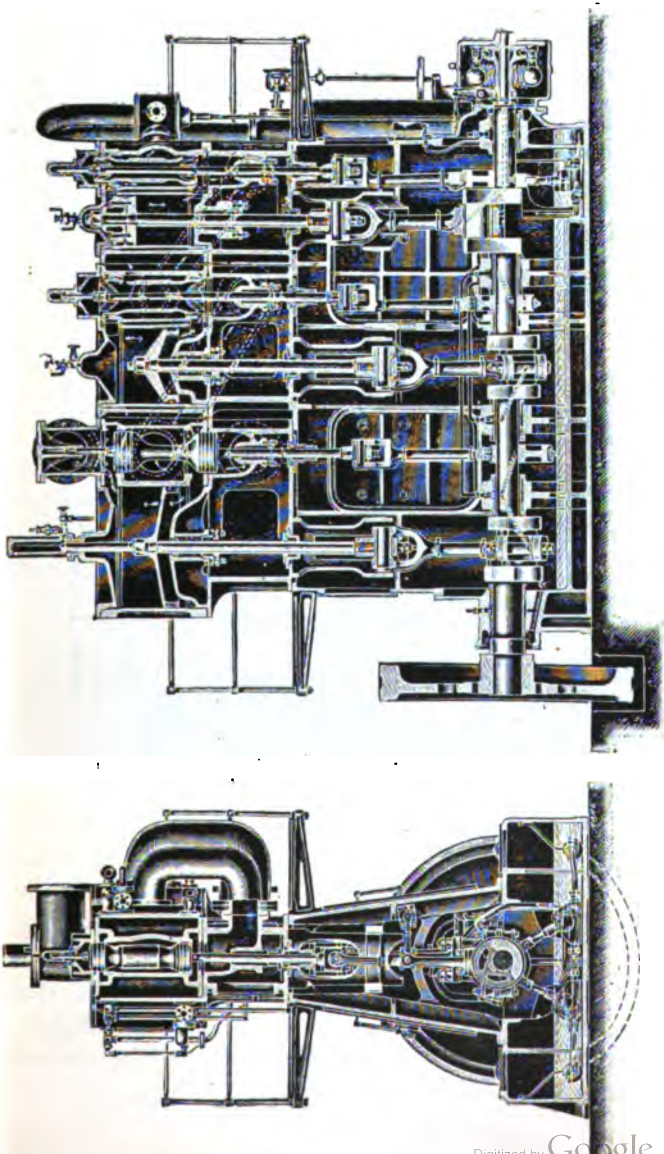


Fig. 96.

upon the size, and the makers[1] claim many advantages for it. Amongst others that:—

(*a*) As the speed is very high the working parts of the turbine are very light, while the special dynamo required is extremely simple in construction, only one or two coils being necessary, and therefore the first cost is low.

(*b*) High efficiency.

(*c*) Small floor space required.

(*d*) No vibration.

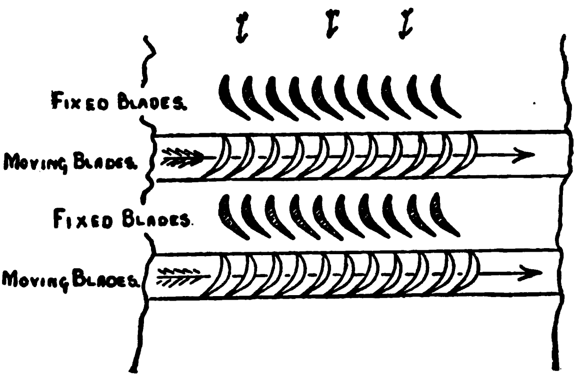


Fig. 97.

(*e*) The steam consumption, while very low, does not increase with the life of the engine.

Briefly described, this engine consists of a cylindrical case with rings of blade projecting inwardly, within which a concentric shaft carrying rings of outwardly projecting blades revolves. The outer blades nearly touch the shaft, while those on the shaft which lie between the others nearly touch the case. Fig. 97 shows a diagramatic view of the blades.

Fig. 98 shows a longitudinal section of the turbine.

[1] Messrs. Clark, Chapman & Parsons, Newcastle.

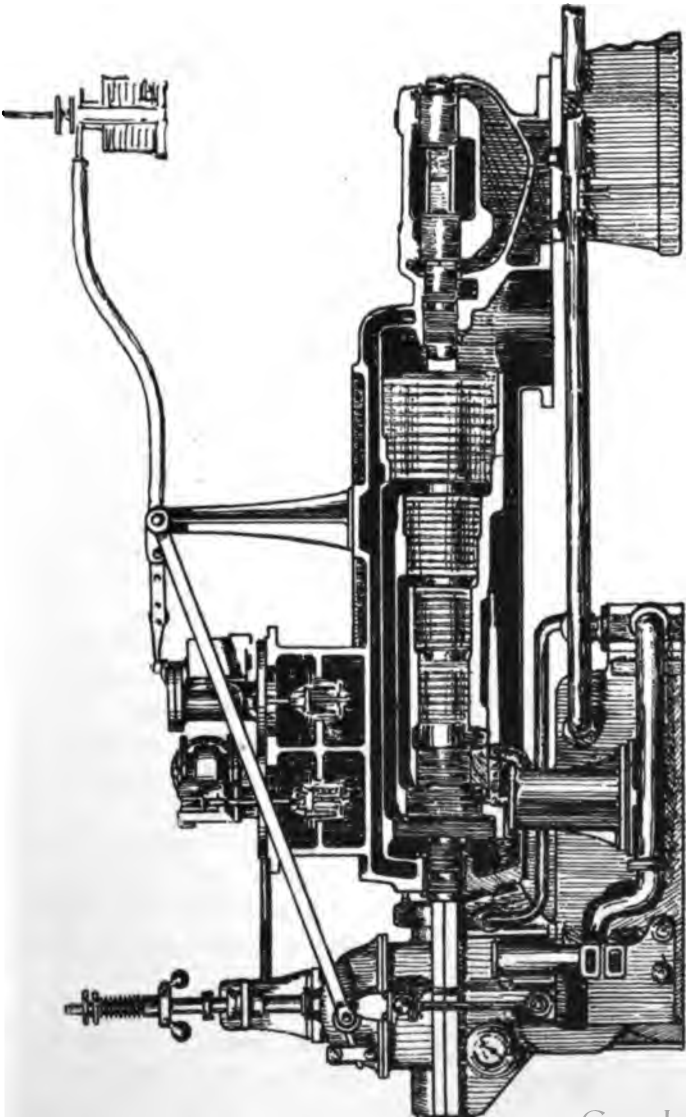


Fig. 98. —Sectional elevation of steam turbine.

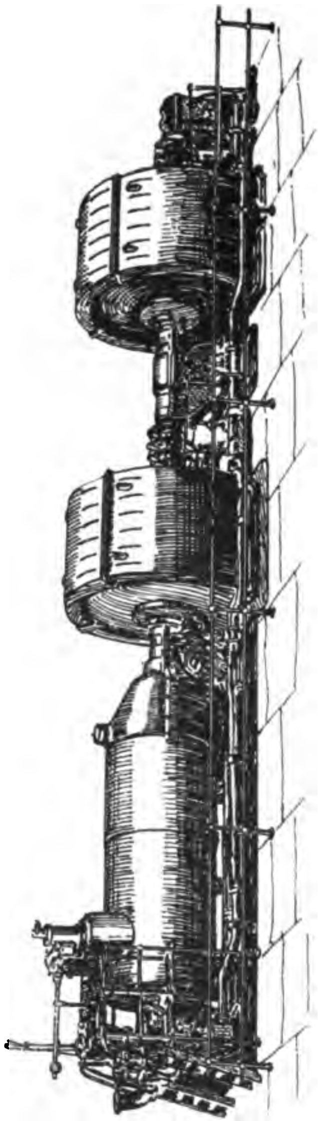


Fig. 99.—4000 k.w. Parsons turbo-alternator.

The steam after entering at A passes through a ring of fixed blades and impinges upon the moving blades, thereby imparting circular motion. The reaction produced by the steam being thrown back upon the next ring of fixed blades increases the force. This is repeated at each of the successive rings of fixed and moving blades, the steam gradually expanding and falling in pressure until the exhaust is reached. The steam is admitted to the turbine in a series of gusts controlled by a double-heat valve operated by a relay governor, which is arranged to increase the length of the gusts of steam as the load on the engine increases and *vice versâ.*

Fig. 99 shows a 4,000 kilowatt combined turbine and alternator, the latter being in two parts in " tandem."

Horizontal Slow Speed.—These engines, which run at from 80 to 100 revolu-

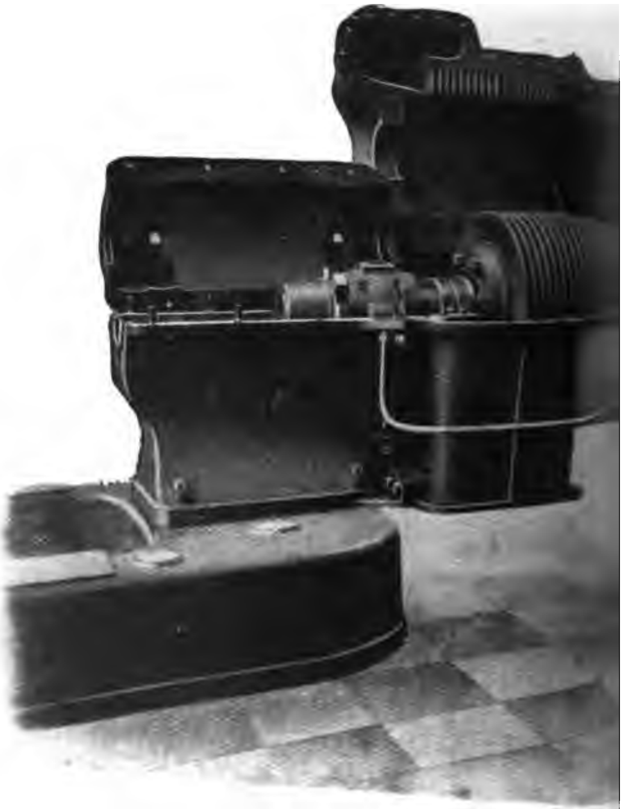
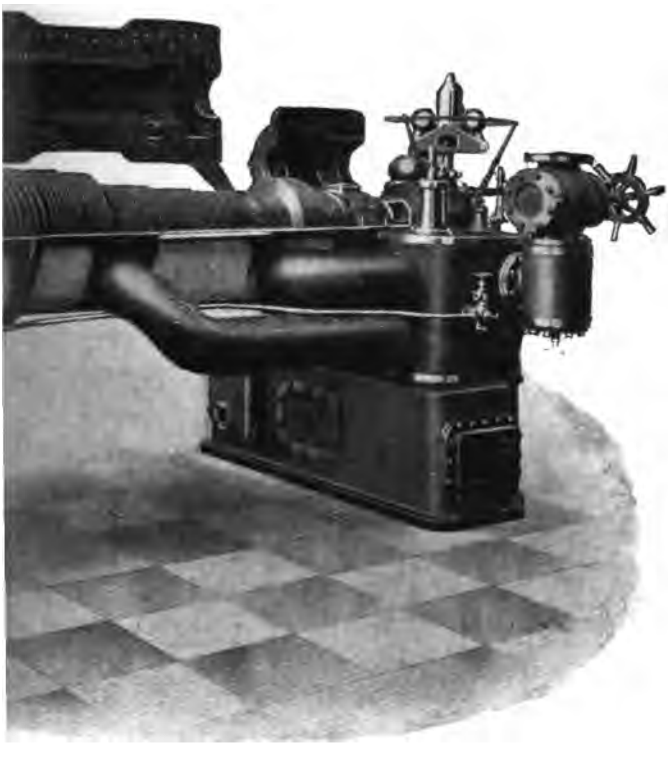


Fig. 99A.—1000 k.w. Willans-Parsons Tu

Recently many of these turbines (Willans-Parsons) have been Richardsons, Westgarth, and Curtis, and there is every evidence t have come to stay, as they are exceedingly economical, and can b majority of reciprocating engines.



ine, showing cover off for examination.

xed and are running as well as Brush-Parsons, Westinghouse,
it not only is there a growing demand for them, but that they
sed with superheated steam of a higher temperature than the

[*To face p.* 240.

tions per minute, are invariably double-acting, and for central station purposes are usually compound, the cranks being arranged on either side of the flywheel.

It is claimed for this type of engine, amongst other advantages, that :—

1. It having stood the test of time its general reliability cannot be questioned.

2. Broken crank-shafts and other parts are of very rare occurrence, while they are notoriously of frequent occurrence with high-speed engines.

3. The engine being spread out, every part is readily accessible while running, and being therefore under continual observation, anything wrong is at once discovered.

4. There is greater freedom from vibration than with high-speed engines, the latter having been the cause of much litigation on account of excessive vibration. As in all horizontal engines the lower portion of the cylinders have to take the weight of the pistons, there is a tendency for both pistons and cylinders to wear unequally and so cause steam leakage. It is desirable therefore, particularly in large engines, that the pistons should be supported by continuing the piston rods beyond the piston head and through the cylinder cover, which must be provided with a bearing and gland.

The outward appearance of all horizontal engines used in central stations is much the same, but considerable variety may be found in the valves and valve gear, and as the efficiency depends almost entirely upon these parts it is intended to deal chiefly with them.

Valves.—One of the chief objections to the earlier form of slide-valve was that with a full head of steam pressing upon the valve (which was usually of large surface area) the weight to be moved by the valve-rods and eccentrics

was very great and put a dangerous strain upon those parts, besides increasing the friction factor of the engine and rendering good governing almost impossible.

Numerous valves have been introduced with a view to overcoming this difficulty, while many different forms of valve gear are in use, whose object it is to insure a quick cut-off.

Piston Valves.—Fig. 92 (Willans), figs. 93 and 94 (Scott), and figs. 95 and 96 (Belliss) show different forms of the piston-valve. In the case of the two former the valve-rod has to take the weight of the steam upon the top valve, which is open to the steam chest, but it is of comparatively small area, and there is no tendency to force the valve against any part of the valve chest. In the latter case the valve is completely in equilibrium. The Willans engine being governed at the throttle, the form of the valves need not be considered in this connection, but the Scott engine is governed by a movement of the valves on their axis, and therefore any serious friction would of necessity interfere with the steady running.

Corliss Valve.—This valve, which is largely used with different forms of trip gear, consists briefly of a semi-cylindrical valve, which works on a spindle in a cylindrical valve chest. The exhaust valve is caused to oscillate by means of a rod and an eccentric; while the steam or admission valve is opened by some special gear that is so arranged as to release it at the point of cut-off desired, and it is then closed suddenly by means of a spring. Except when the port is closed there is no tendency to force the valve against the seat, and there is consequently very little friction. Figs. 100, 101, and 102 illustrate Corliss valves and gear as now made by one firm.[1] Fig. 102 is a

[1] Messrs. Yates & Thom, Blackburn (Dobson's patent).

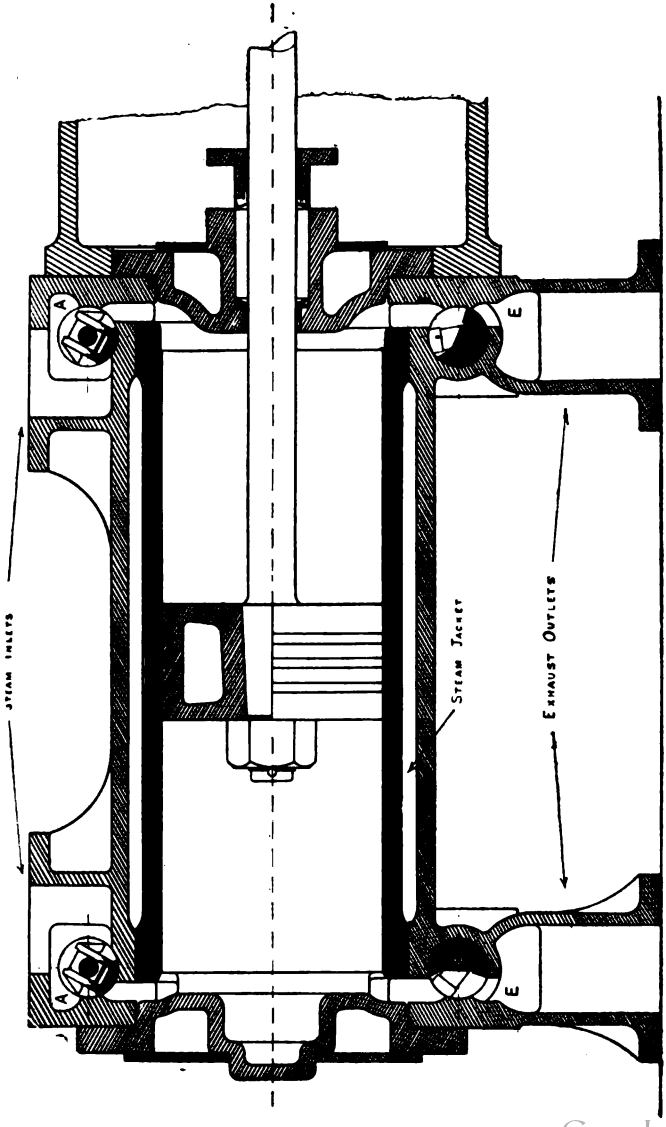


Fig. 100.

side elevation of a cylinder with valve gear. The exhaust valves, E, E, are oscillated, as shown, by means of the exhaust eccentric, and disc, rods, and levers. The steam or admission valves, A, A, are actuated by the trip gear as follows (as both valves are moved in the same manner,

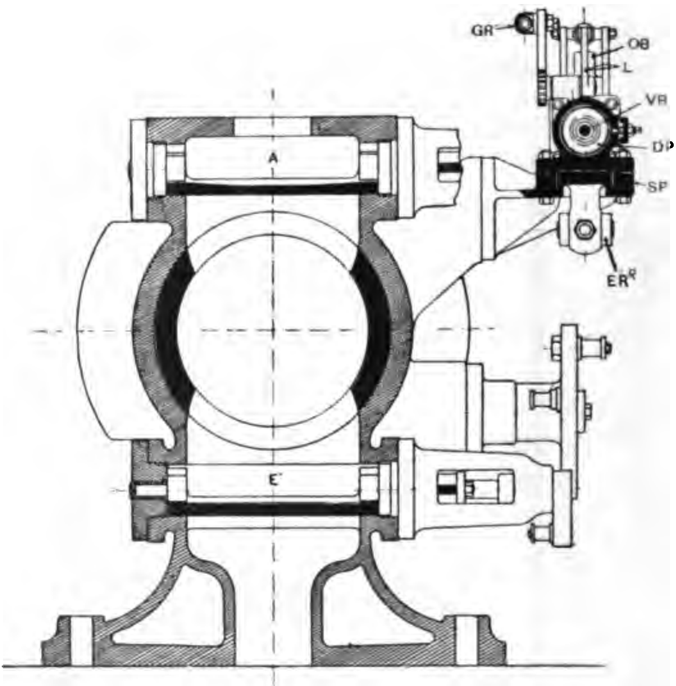


Fig. 101.

but in opposite directions, it will be sufficient to describe one side only):—

Attached to the eccentric-rod, E R, is a slide plate, S P, carrying on the end the catch box, C B, containing a drop block, D B, held down by a spring, S, for engaging with the

valve-rod, V R, which operates the valve A through the lever L. The dash pot, D P, contains a spiral spring, S S,

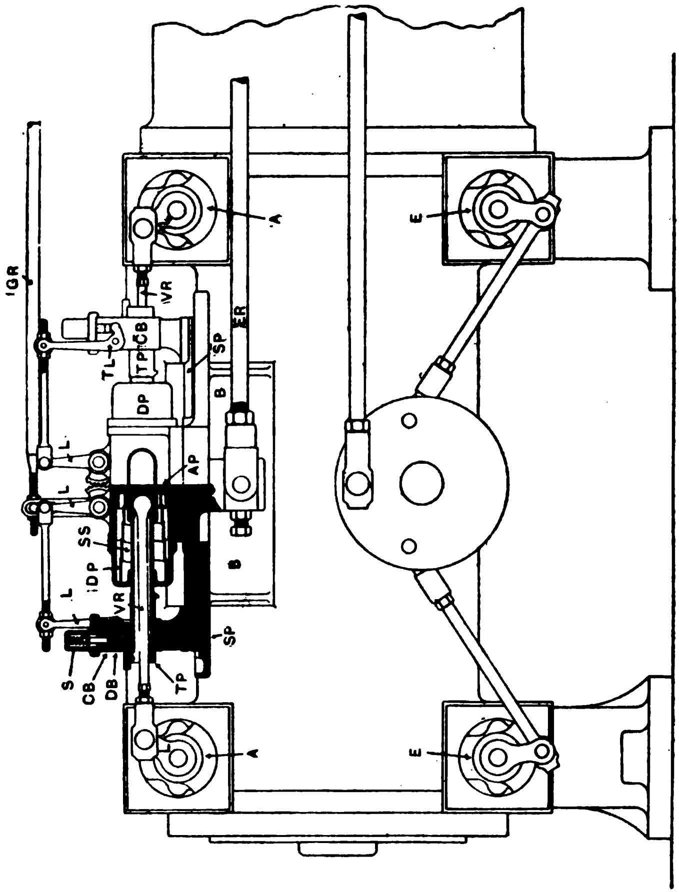


Fig. 102.

for closing the valve, and an air plunger, A P. The whole is carried on the bracket, B. As the slide plate and catch

boxes reach the end of the stroke, the drop piece engages with the hollow-trunk piece, T P, connected to the dash-pot piston, through which passes the valve-rod, V R, connected to the lever L on the end of the valve spindle. As the slide moves forward the catch box draws out the trunk

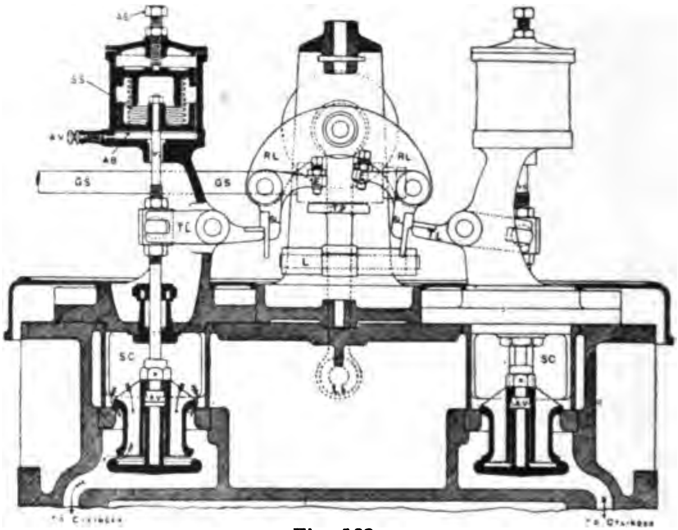


Fig. 103.

piece, at the same time opening the valve, which remains open until the drop block is lifted clear of the trunk piece by the toe lever, T L, when the spiral spring, S S, in the dash pot forces back the piston and closes the valve. The trunk piece is now left in position ready for the next stroke. The point of cut-off is determined by the governor acting upon the toe lever, T L, through the lever L and the rod connecting it with the toe lever.

Fig. 101 shows a transverse section of cylinder and valve gear, and fig. 100 shows a longitudinal section through the cylinder.

Proell Valves and Gear.[1]—Figs. 103 and 104 illustrate the Proell valves and gear. It consists of two equilibrium admission valves, A V, A V, one at each end of the cylinder, which are alternately lifted by means of the valve spindles, V S, V S, in connection with the trip levers, T L, T L. The

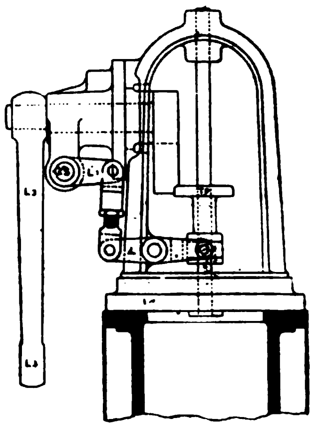


Fig. 104.

ends of these levers are depressed by the supplementary levers, S L, S L, which are hung on the opposite ends of the rocking lever, R L, R L, worked from the eccentric by the valve-rod attached to the lever L_3. The ends, E, E, of the levers S L, S L projecting towards the centre are brought into contact at each stroke with the trip pad, T P, which is controlled by the governor through the levers L_1 and L_2 and the governor shaft, G S. The moment of cut-off is determined by the height of the trip pad, T P; for, as soon as the end, E, of either of the levers S L, S L touches

[1] Messrs. Marshall, Sons & Co., Gainsborough.

the trip pad, T P, any further movement of the rocking lever, R L, R L, disengages the lever S L from the trip lever, T L, and the valve is immediately closed by the spiral spring, S S, in the box at the top of the valve spindle, V S. The closing speed of the valve is regulated by the adjusting screw, A S, while the air buffer, A B, is regulated by the air valve, A V, enabling the valves to close rapidly and silently. The path of the steam from the steam chest, S C, S C, past the admission valves, A V, A V, into the cylinder is shown by arrows in the figures.

If the admission valves, A V, A V, were each in one piece, they would be useless for the purpose, on account of the steam pressure on the top, but by dividing them into two parts they at once become equilibrium valves, and the shell is readily lifted from the seat by the trip gear, as shown.

Wheelock Valves and Gear.[1]—These valves and gear differ from the two previously described in many ways, but more particularly in the following points:—

(*a*) The valves are of the grid or slide-valve pattern.

(*b*) Both the main and exhaust valves are worked from one eccentric instead of two.

(*c*) Both valves as well as the valve seats are contained in one shell or plug, which can be withdrawn from the valve chest without dismantling.

Fig. 107 shows the trip gear, the action of which is described below (as the action is the same on both sets of gear, but in reverse directions, it will suffice to describe one set):—

The eccentric-rod, E R, is attached to the valve-rod, V R, which therefore oscillates in the usual manner. On the

[1] Messrs. Daniel Adamson & Co., Dukinfield.

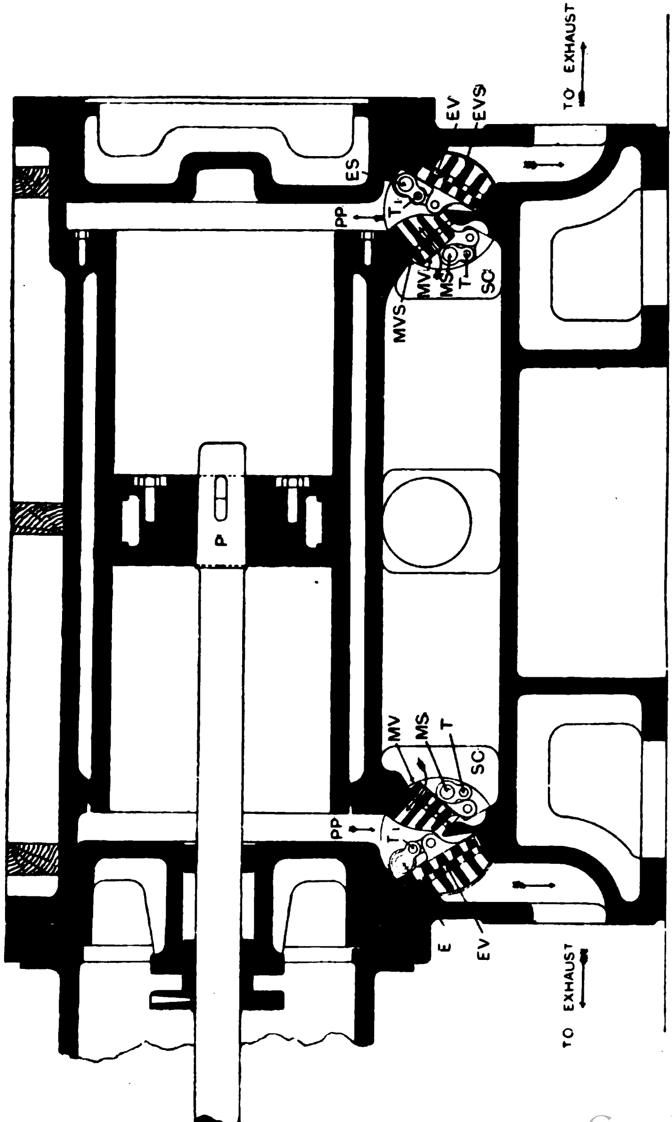


Fig. 105.

valve plug, V P_2 (right side of figure), is the lever L_1, which is attached at the upper end to the valve-rod; it is also attached to the exhaust-valve spindle, E S, and at the lower end, by means of a pin, to the latch link, L L. When the valve-rod, V R, moves to the right the latch link, L L, is moved to the left, and the end of the hard steel plate, S P, engages in the trip block (not shown) on the lever L_2, which is attached at the lower end to the main valve spindle, M S, and at the upper end to the plunger-rod, P R. The valve-rod, V R, now moves to the left, and the latch link, L L, is pulled to the right, moving with it the lever L_2, and opening the main valve by means of the spindle, M S. As the movement continues the curved horn, C, on the latch link encounters a projecting cam or tooth on the disc, D. This tooth causes the horn to lift and releases the lever L_2, which is caused to fly back by means of a spring in the dash pot, D P, thus closing the valve. The moment of cut-off depends upon the position of the tooth on the disc, D, and is determined by the governor acting on the governor-rod, G R, and the lever L_3. A plunger on the end of the plunger-rod, P R, and working in the dash pot, D P, acts as an air buffer and causes the gear to work silently. By lifting the handle, H, at the end of the eccentric-rod the latter is disengaged from the valve-rod and the trip motion can then be worked by hand by means of the handle, H.

Fig. 105 shows a section of the valves, steam chest and passages, and the piston. S C is the steam chest, and M V the main valve, which slides on the seat, M V S. When the latch link, L L (fig. 106), engages in the lever L_2 (also fig. 106), and pulls it over, as just described, the spindle M S is turned partly round, and the valve is opened by means of the toggle joint, T, and the steam passes into the cylinder

through the ports, P, P. The piston, P, now moves forward, and at the point of cut-off desired the valve suddenly closes, cutting off the steam. The steam behind the piston now expands until the point of exhaust is reached, when the exhaust valve, E V (which slides on the seat, E V S), is opened by means of the spindle, E S, and the toggle joint, T, and the steam passes into the exhaust. Although the

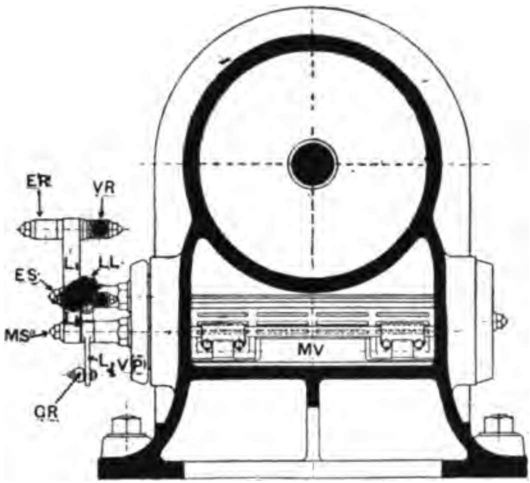


Fig. 106.

exhaust valve spindle, E S, is connected direct to the lever, L_1, as before described (fig. 107), the peculiar action of the toggle joint, T, keeps the valve closed until towards the end of the stroke.

The very short travel of the valves and the arrangement of the toggle joints give almost instantaneous opening and closing, with great ease of action even under extreme pressures. By this arrangement also the valves are allowed to dwell or rest during the period of exhaust and steaming respectively.

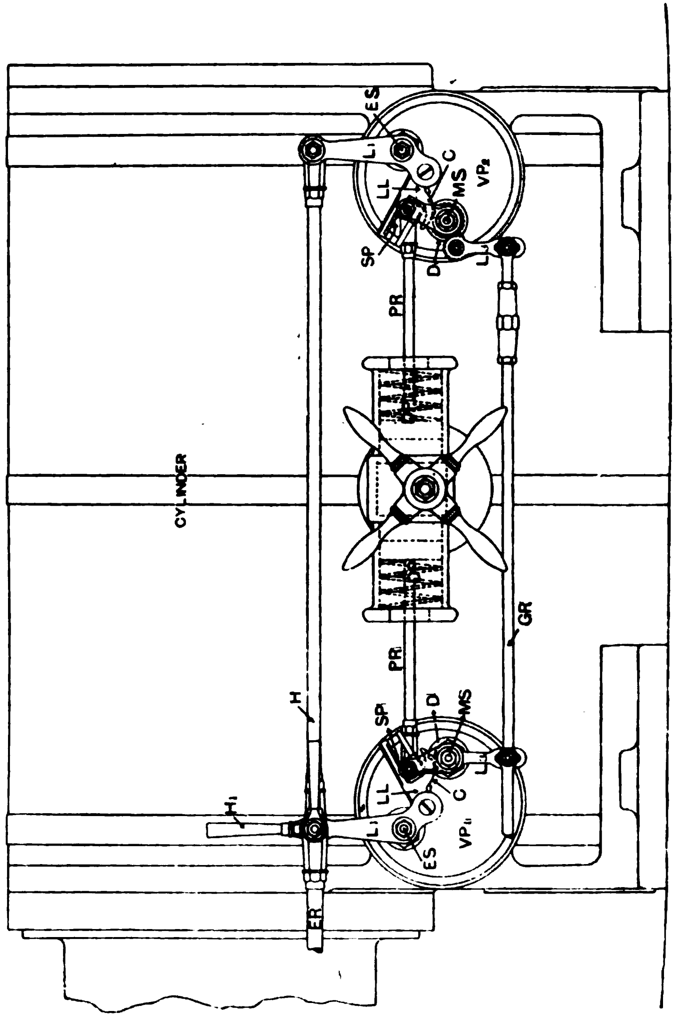


Fig. 107.

Fig. 105 shows a transverse section of the valve plug with the main and exhaust valves and valve seats.

Condensing.—Where a plentiful supply of water is at hand the cost of fuel may be materially reduced by using condensing engines.

If a compound non-condensing engine consumes, say, 20 or 22 lbs. of steam per i.h.p. per hour at full load, the addition of an efficient condenser may reduce this consumption to, say, 14 lbs., or even less.

The duty of a boiler is to evaporate water into steam, while that of a condenser is to condense the steam into water. In a non-condensing engine the steam exhausts into the atmosphere at, say, 4 or 5 lbs. above the atmospheric pressure, while in a condensing engine this back pressure is reduced to several pounds *below* it.

Condensers may be divided into three types, viz. :—

(*a*) Surface.
(*b*) Ejector.
(*c*) Jet.

(*a*) A surface condenser consists of a number of metal tubes enclosed in an outer shell (somewhat similar to a feed-water heater). Through the tubes a constant circulation of cold water is maintained. Around the tubes and inside the shell the exhaust steam passes, and on coming into contact with the cold surface of the tubes it is condensed, the temperature of the circulating water being raised to a degree dependent upon the surface area of the tubes, the quantity of water flowing, &c. In order to get rid of the water into which the steam has been condensed, as well as the air which has been carried over with the steam, a pump (which is frequently attached to and forms part of the engine) is used.

One form of surface condenser known as an evaporative condenser is popular, particularly in London, where water is expensive. It consists, as the illustration shows (fig.

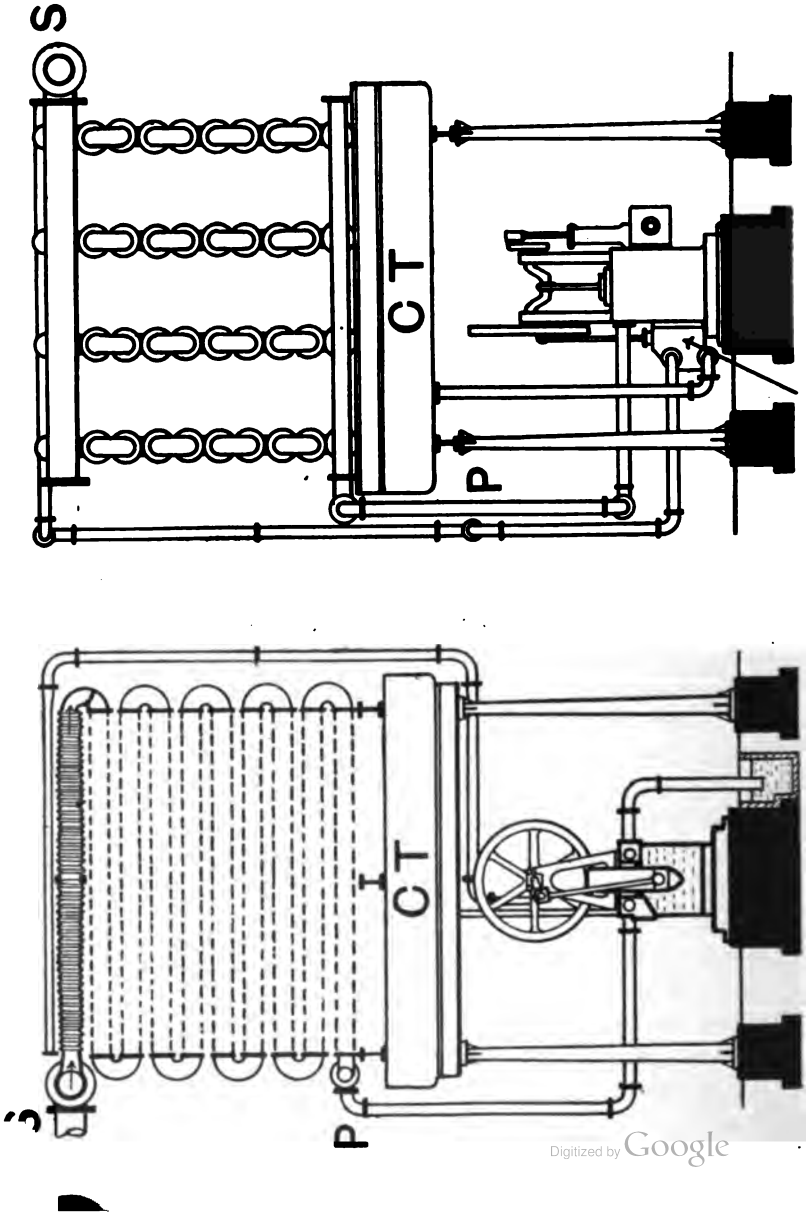


Fig. 108.

108),[1] of a series of pipes, through which the exhaust steam passes, and over the outside of which cold water is caused to trickle in small quantities ; the rapid evaporation of the water carrying off the heat and so cooling and condensing the steam. The quantity of water required to maintain a good vacuum varies from one-half to seven-eighths of the feed supply to the boiler. Where ground space is not available, the condenser is frequently erected upon the roof.

Referring to fig. 108,[1] the exhaust steam enters at S, and, after passing through the system of pipes and being condensed, is conveyed by the pipe, P, to the pump and thence to the hot well. The cooling water is circulated by the circulating pump, C P, and flows through the circulating pipe to a series of perforated pipes arranged over the top of the condenser. The water then passes over the condenser and falls into the collecting tank, C T, from whence it again passes to the pump, when the operation is repeated.

Fig. 109 shows a surface condenser with cooling tower and fan attached to a horizontal engine and direct-driven dynamo; D is the dynamo and engine, H high-pressure cylinder, L low-pressure cylinder, E E exhaust pipe to condenser C, A P air pump, H W hot well for receiving the condensed steam, C P circulating pump by which the cooling water is pumped from the tank, T, through the circulating pipes, P P, and condenser, C, thence to the cooling tower, C T, and back to the tank. The cooling tower is of the inclosed or chimney-type, and is provided with a fan, F, to assist in cooling the water.

Fig. 110 shows a condenser, pumps, and cooling tower, in plan, the lettering being the same as the last.

[1] Ledward & Co.

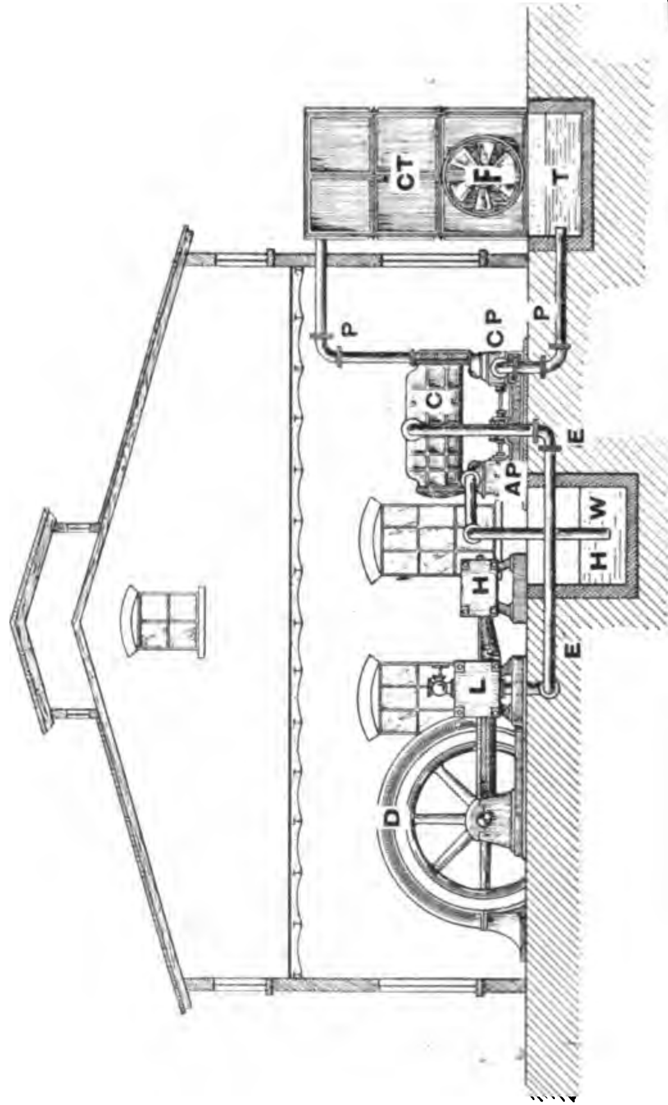
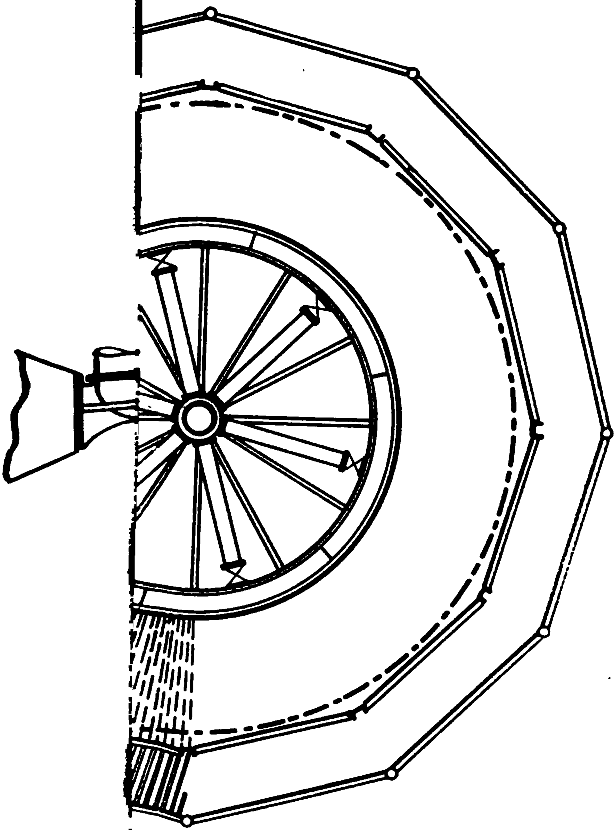


Fig. 109.



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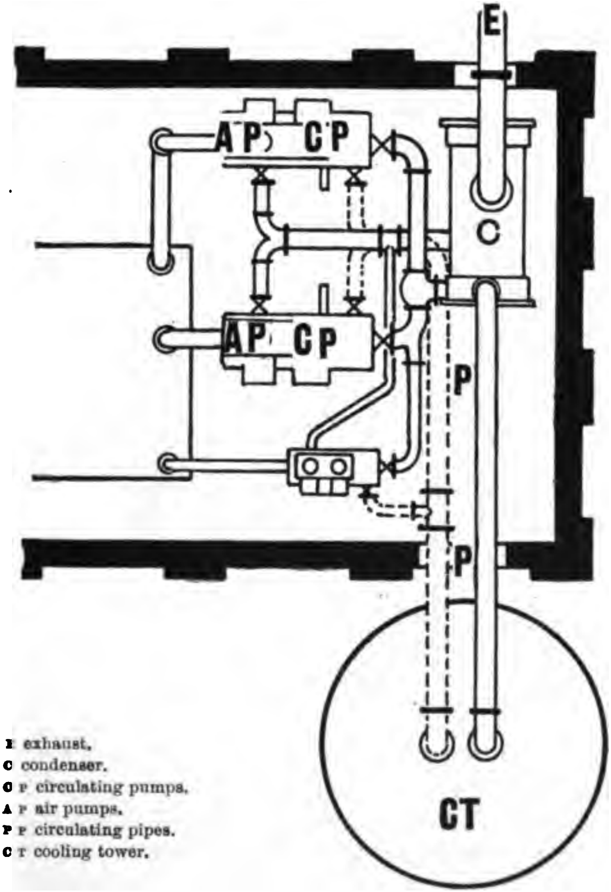


Fig. 110.

(*b*) Fig. 111 illustrates a section of an ejector condenser.[1] The cooling or condensing water enters at W, and, passing

[1] Messrs. Körting Bros., London.

vertically downwards through the condensing tube, C T, is ejected at E.

The exhaust steam enters at E S, and, passing through the holes in the perforated tube, T T, mixes with the water, is condensed, and is ejected with the water at E. When the source of the cooling water is at a lower level than the condenser, live steam is admitted at L S in order to start it flowing, after which the momentum imparted to the water by

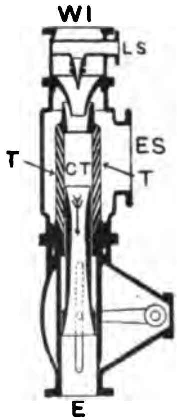


Fig. 111.

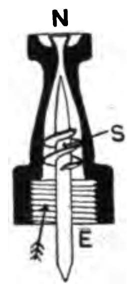


Fig. 112.

the velocity of the exhaust steam is sufficient to enable the water and air to pass out against the atmospheric pressure.

In this case it will be seen that no pump is necessary.

(*c*) In a jet condenser the exhaust steam is condensed by being caused to flow against a jet of water inside a closed chamber. The condensed steam, as well as the air and cooling water, are then carried off by means of a pump, as in the case of the surface condenser.

Where water has to be paid for, it is customary to use the condensing water over and over again after it has been

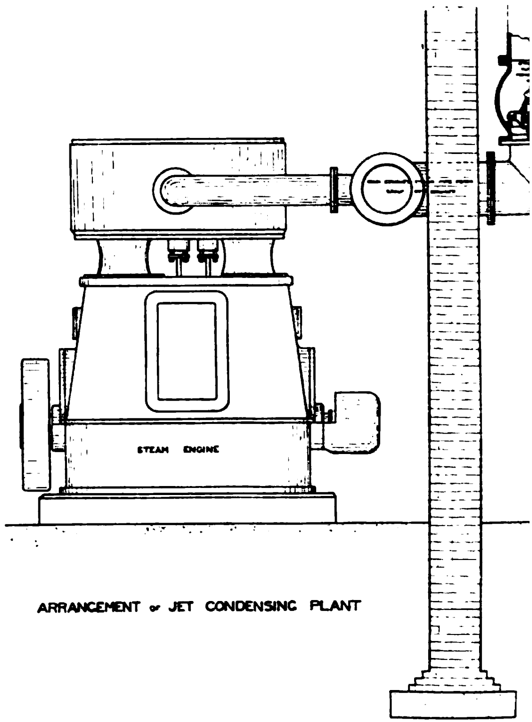
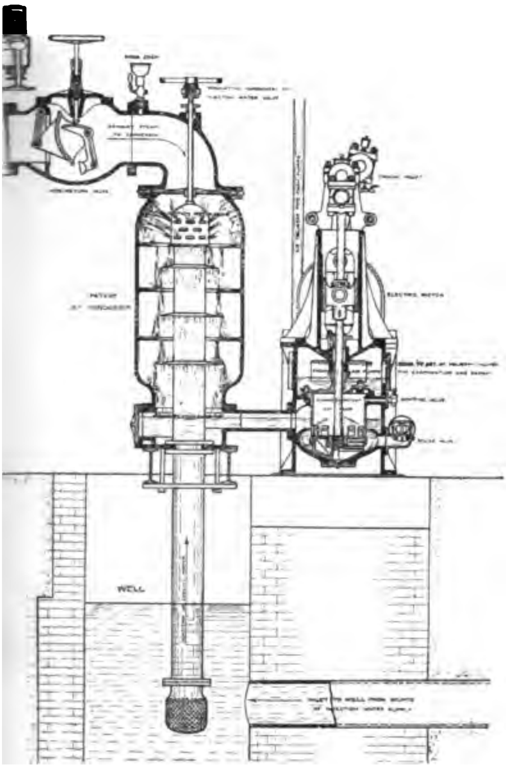


Fig. 112A.—Sectional view of Counter Current
Electricity Works), Messrs. Bertrams, Li



Condenser and Edwards' Air Pumps (Hanley
ed, St. Katherine's Works, Edinburgh.

[To face p. 259.

cooled by artificial means: a part, however, is lost as vapour, and cannot be recovered. Many cooling devices are in use: in some cases numerous sheets of metal or other material are used, over which the water is distributed in a thin film, and is cooled by contact with the air;[1] in other cases a fan is used to produce a blast of air which passes between vertical plates, down which the water is slowly flowing. By another arrangement the water is forced by means of a pump through a series of pipes over a pond or tank. Attached to the pipes are a number of jets or outlets, constructed in such a manner that the water passes out in the form of spray, in which state it is readily cooled. Fig. 112 shows a section of such a jet.[2] The warm condensing water enters at E, and, travelling around the spiral, S, on the fixed spindle, acquires a rotary motion, and on issuing from the nozzle, N, flies by centrifugal action into small drops.

A Bertram counter current condenser is shown in fig. 112A. A description is given on the plate.

SEPARATE CONDENSERS may be used for each engine, or one large one may be utilized to condense the steam for a number of engines, but in all cases it is desirable that the condensers should be as close to the engines as possible, in order to avoid long exhaust pipes, which are liable to develop leaky joints, and so materially reduce the vacuum. Self-acting valves are usually attached to the exhaust pipe, which open the exhaust to the atmosphere in the event of a loss of vacuum from any cause. Where the condensed steam is used as hot feed, it must be passed through an oil separator before passing into the condenser, and the water should be subsequently filtered.[3]

[1] Fig. 109A shows a cooling tower of this type (Barnard Wheeler).

[2] Messrs. Körting Bros., London.

[3] See Separators.

CHAPTER VIII

ELECTRICAL EQUIPMENT

Coupling of Prime Mover and Electrical Generator.—In considering the electrical equipment of a central station, the most important piece of apparatus is, of course, the dynamo,[1] as electric lighting, considered from a commercial standpoint, would not be possible without it; and although we may some day be able to economically transform heat directly into electrical energy without the inter-

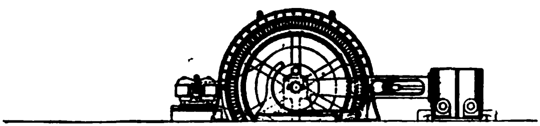


Fig. 113.

mediate use of the boiler, engine, and dynamo, the latter is of itself a highly efficient means of transforming energy, and but little improvement in its efficiency is possible.

Dynamos may be driven direct by being coupled to the shaft of the engine, or being built around the flywheel and forming part of the engine (fig. 113), or they may be driven by means of belts or ropes from the flywheel, but this method is now quite obsolete.

[1] The term "dynamo," as used in this section, includes continuous-current and alternating-current machines, and may be regarded as the equivalent of "electrical generator."

Central Station Generators.—The selection of the dynamo is a matter of serious importance and requires careful consideration. A few years ago nearly every manufacturer had some distinctive pattern upon which his dynamos were built, but the disappearance of all but two or three forms illustrates somewhat forcibly the law of the survival of the fittest. Continuous-current dynamos used for central station work, up to 200 or 300 kilowatts capacity, are now almost invariably of the vertical or inverted horseshoe or bipolar magnet type with drum armature, except those used for series arc lighting; for larger sizes, four or more poles are used. Provided the efficiency is not affected, the form of dynamo is of but secondary importance to the station engineer. The following points are, however, of the first importance, as the success and continuity of the supply largely depend upon them.

(*a*) *Solidity and Durability.*—Manufacturers at one time seemed to pride themselves upon turning out dynamos having a maximum capacity with a minimum of weight, but as their sole merit probably lay in their low first cost (the questions of reliability and upkeep being apparently overlooked), machines are now invariably built of a much more solid and durable character.

If steady running and freedom from vibration is aimed at—as it, of course, should be—a heavy frame and bedplate is essential. The shaft should be composed of high quality steel, and of sufficient diameter to resist any accidental stress that may be thrown upon it, without risk of springing or other injury. The armature should be perfectly balanced and the conductor so wound or secured as to prevent loosening due to centrifugal force or other cause.

(*b*) *Heating.*—Continuous running at full load without excessive heating of the commutator or the armature or magnet coils is essential, the result of over-heating being that, sooner or later, the insulation will be destroyed and breakdown occur. The current density in both armature and magnet conductors should never exceed 2,000 ampères per square inch cross-section at full load.

(*c*) *Commutator and Brushes.*—In order to avoid undue wear of the brushes and commutator, it is necessary that the machines should run at all loads without sparking. The commutator should be sufficiently long and the segments and brushes of sufficient cross-section to enable any brush to be lifted for adjustment or cleaning, without overloading the remainder. The brushes should be duplicated, so that adjustment may be effected without interrupting the supply or stopping the dynamo, and the brush holders so arranged that all the brushes are readily accessible while the machine is running. The commutator should permit of considerable turning down as wear occurs, so that frequent renewals are unnecessary.

(*d*) *Bearings and Lubrication.*—The bearings should be long, so as to allow ample surface, and it is now customary to make the length from two and a half to three times the diameter of the shaft. Removable steps or brasses are necessary, and they are usually made in two or four sections for convenience and adjustment. Some engineers favour gun-metal or similar hard metal, while others prefer a soft white metal, of the Atlas, Magnolia, or Babbitt metal type. Others, again, compromise matters, and use brass or gun-metal with slots in the surface filled in with white metal.

In the event of a bearing heating, gun-metal or hard brasses are liable to close in and grip the shaft, pulling the

engine up, and sometimes seriously straining the shaft or scoring the journal. Should this occur when a dynamo is running in parallel, the result may be serious, unless automatic cut-outs on the dynamos are provided. With white metal there is probably less liability to heat, and if it occurs, the metal runs out; in both cases a temporary disablement of the plant occurs. Bearings that are liable to heat are a perfect bugbear to the engineer of a central station, and for this reason they are sometimes provided with a water jacket. This consists of an outer closed chamber surrounding the brasses, and through which cold water may be made to circulate, thus tending to keep the bearing cool, and although it should be unnecessary to use it continuously it is useful on emergency.

The efficient lubrication of the bearings is specially important, and numerous devices have been invented for the purpose of maintaining a continuous supply of oil to these parts, the idea being in all cases to keep the oil circulating through the bearing. This is sometimes effected by means of a small pump driven from the dynamo shaft, which lifts the oil from a tank and forces it through the bearings, after which it flows back to the tank to be pumped up to the bearing again, and so on. In another arrangement the pedestal of the bearing forms the tank, and a toothed wheel or other apparatus attached to the shaft, and running in the oil, catches the latter and throws it over the journal, around which it passes, and then returns to the tank again, thus maintaining a constant circulation. Considerable economy is claimed for all these forms of lubrication over the separate sight-feed type, and more perfect lubrication, and therefore less liability to heating. Solid or grease lubrication is also used, but more frequently on engines than dynamos.

(*e*) *Repairs and Renewals.*—The dynamo should be so constructed that when repairs are necessary the part requiring attention may be accessible with the least possible interference with the other parts. When sectional brasses are used in the bearings, it should be possible to remove the bottom brass with a very slight lifting of the shaft, and without removing the armature. It should also be possible to remove the armature without dismantling the machine. All heavy pieces requiring the use of a crane or jack should be provided with lugs or eyebolts in order to facilitate their removal. All the wearing parts and those that may require renewing should be made strictly to gauge, and duplicates provided, so that in case of accident repairs may be facilitated. The design of alternators should be such as to permit of the removal of damaged coils and their replacement after repair, or substitution of new ones, in a very short time.

(*f*) *Efficiency.*—A reasonably efficient dynamo is essential to the economical running of a station, and it goes without saying that, all other things being equal, the most efficient should be chosen. Reliability, however, is of even greater importance than efficiency, and it is better to sacrifice 1 or 2 per cent. of the latter, if by so doing the former is materially increased.

The electrical efficiency of first-class dynamos averages about 94 or 96 per cent.

Continuous-current Dynamos. — Continuous - current machines are made of three types, viz:—

(*a*) Series wound.

(*b*) Shunt wound.

(*c*) Compound wound.

(*d*) The series wound machine is that in which the armature winding and the outer circuit is in series with

the magnet coils. For a given speed its pressure rapidly falls as the resistance in the circuit increases. Except for street-lighting purposes, this machine is now practically obsolete as far as central station work is concerned.

(*b*) The magnet coils of the shunt machine are connected directly across the armature terminals,[1] and therefore forms a shunt circuit to the armature and external circuit. As the resistance of the magnet coils is very high in proportion to that of the armature conductor, only a small portion of the current passes through them. For a given speed the pressure rises as the resistance of the external circuit increases, and consequently this type is specially adapted for charging storage cells, and is largely used for central station purposes. By means of a resistance and regulating switch the current in the magnet coils can be varied and the pressure at the dynamo terminals regulated. Shunt machines can be designed to give a practically flat characteristic at constant speed.

(*c*) The compound wound dynamo is, as its name implies, a mixture of two types. Its magnets are wound with a shunt coil through which a small shunted current passes, and also a series coil, through which the total outgoing current from the armature to the circuit passes.

It is evident that at a given speed the terminal pressure will remain more constant with a varying load than is the case with either a shunt or series machine, each coil tending to compensate the defects of the other. A resistance and regulating switch (as in the shunt dynamo) enables the pressure to be varied at will.

Parallel Running of Continuous-current Dynamos.—(*Shunt Machines.*)—The running of continuous-current

[1] Or some method equivalent to this. See Excitation in Chapter IX. on "Switch Gear."

dynamos has never presented any serious difficulty when shunt wound machines have been used, and the advantages of running in this manner, instead of supplying separate mains, from separate dynamos, are obvious. When a number of machines are run in parallel, all their positive terminals are coupled to the positive bus bar and their negative terminals to the negative bus bar of the station, and so answer the same purpose as one large dynamo whose capacity is equal to the joint capacities of the whole. In the case of one large dynamo, however, it would be running during the greater part of the twenty-four hours with only a very small load, and therefore very inefficiently, to say nothing of the fact that another large dynamo of equal capacity would have to be held in reserve in case of accident. Parallel running enables the plant to be run at or near its best load, as one machine after another can be run up and coupled in as the load increases, and thrown out again as it goes off, while a reserve of one machine out of four or five (provided they are all of equal capacity) is usually sufficient. Dynamos having different capacities may be coupled to the bus bars or together in parallel, provided their pressures are equal, the variable shunt being so adjusted that each takes its proper proportion of the load.

Before coupling a dynamo to the bus bars it should be run up to its normal speed and its pressure adjusted a trifle higher than that of the others; it can then be switched in and adjusted for load, and provided the difference in pressure between the machine and the bus bars at the moment of coupling is not too great, the pressure on the mains will not be disturbed, and consequently no flicker of the light observed. Should the pressure of a dynamo fall from any cause below that

of the others, it would receive current instead of giving it, and tend to run as a motor, the direction of rotation (in the case of a shunt dynamo) remaining the same.

The current in the field-magnet coils of a shunt wound machine flows in the same direction, whether it is giving current as a dynamo or receiving it as a motor, and the polarity therefore is unaltered. With a series wound machine the case is very different, and a back flow of current into the dynamo reverses its polarity.

Compound Dynamos.—Should a back flow of current through the series coil of a compound dynamo occur sufficient to overcome the magnetizing effect of the shunt coil, a similar reversal of polarity would result. Hence the running of compound machines in parallel requires greater care than is necessary with shunt dynamos, and special precautions have to be taken to prevent reversal of polarity, and consequent short-circuiting of all the other dynamos in the parallel.

It is for this reason, and the greater complication involved, that compound machines are not more generally adopted for central station work and are rarely used.

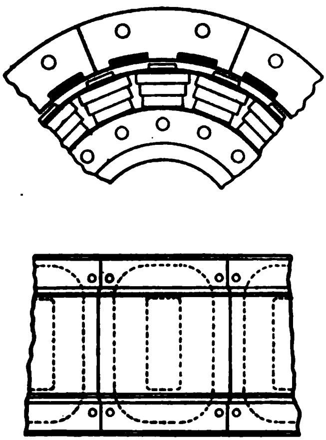
In case of accident, such as the breaking of a crank-shaft and the sudden stoppage of a dynamo, the whole of the machines would be at once short-circuited if some means were not provided to prevent it. This usually takes the form of an automatic cut-out or non-return switch, which opens the current of the faulty dynamo when the current given by it falls below a pre-determined limit.[1]

Alternators.—The alternators at present in the market, or that have been introduced and have prematurely disappeared, are many and various, the inventors in every

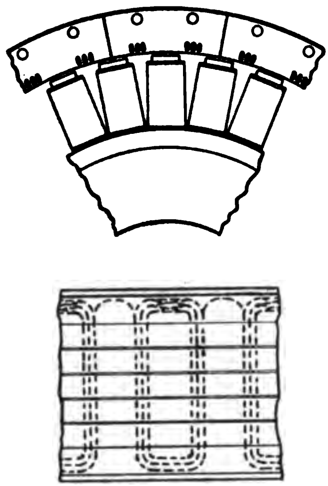
[1] See section on Non-return Apparatus in Chapter IX. on "Switch Gear."

case claiming some special advantages for their particular type of machine over that of all others. Some have iron in the armature and some are without, some whose field magnets rotate and whose armature is a fixture, and others whose armature rotates and whose field magnets are fixed, producing various periodicities from forty periods upwards. The makers of alternators having no iron in the armature claim that their machines are distinctly superior, inasmuch as the co-efficient of self-induction is low, and that they are more suitable for parallel-running than a machine whose co-efficient of self-induction is high; while, on the other hand, manufacturers of alternators whose armature possesses an iron core claim that in order to run in parallel successfully a high co-efficient of self-induction is necessary, that in the event of a short-circuit in the system the back E.M.F. prevents a dangerous rush of current through the armature. Makers of fixed armature machines claim that their particular type of apparatus can be made much stronger mechanically, that the insulating material is not subjected to the severe mechanical stress which machines with rotating armatures are subjected to, and that therefore the insulation is more reliable; that as alternators are invariably used for the generating of high-tension electricity, the whole of the high-tension section of the machine can be securely covered and protected against accidental contact, which is not possible when the armature rotates, as the collectors and brushes have to be attended to. Makers of rotating armature machines, on the other hand, claim that in manufacture they are less costly, particularly when there is no iron in the armature. Similar difference of opinion exists in regard to periodicity, those who favour fifty or sixty periods claiming that their machines run much better in parallel than

those of their rivals with periodicities of eighty to one hundred, that in consequence of the longer phase there is greater elasticity between the armatures of the two machines in parallel; while those who favour high periodicities hold directly the opposite, and state that as there are a greater number of impulses per second, tending to keep the machine in phase, there is less inclination to get out of step. The same arguments are, of course, used



Figs. 114 and 115.



Figs. 116 and 117.

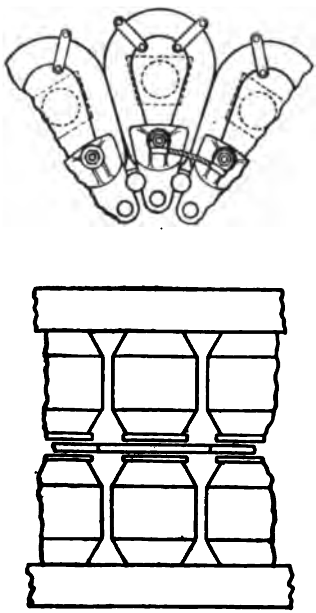
as to the suitability of high and low periodicities for motors.

Monophase alternators may be divided up into four types as follows:—

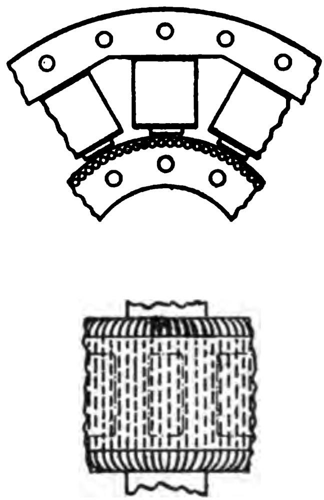
(*a*) ***Face-coil Armature with rotating magnets.***—This type of machine (figs. 114 and 115) consists of an outer flat ring of laminated iron, on the inner face of which is laid the armature coils.

Within the ring rotate the magnets, which are arranged radially around a wheel, the poles projecting towards, and within a short distance of, the armature coils.

(*b*) *Tunnel-wound Armature with rotating magnets.*—As in the last case, the armature possesses an outer flat



Figs. 118 and 119.



Figs. 120 and 121.

ring of laminated iron (figs. 116 and 117). Holes are drilled through the iron parallel with the face, and the armature conductor is threaded through. The field magnets rotate and are arranged as in the last case. A variety of the tunnel-wound armature is known as the slot-wound, where the coils are laid in slots cut in the iron case.

(*c*) *Bobbin or vertical-coil Armature with fixed magnets.*

—In this type (figs. 118 and 119) the armature coils are arranged radially around a wheel on the shaft.

The field magnets form two rings on either side of the armature, which rotates between them.

(*d*) *Drum-wound Armature with fixed magnets.*—The armature of this machine is in the form of a drum—similar to a continuous-current dynamo—and runs on a shaft between the poles of the magnets (figs. 120 and 121).

As will be seen, types *a* and *b* have fixed armatures, the field magnets being the revolving part, while types *c* and *d* commonly have rotating armatures and fixed

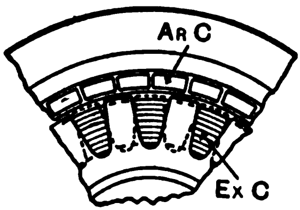


Fig. 122.

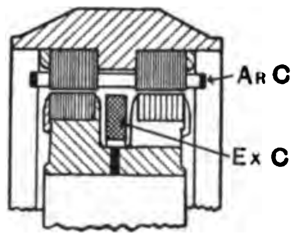


Fig. 123.

magnets, the principal exceptions to the rule being in the case of the Mordey[1] machine (type *c*), and in the Val Fynn machine (figs. 122 and 123), in which the armatures are fixed and the magnets revolve.

(*e*) A fifth type is known as the inductor alternator, in which both armature and magnets are fixed, and a disc or some other form of iron inductor rotates between them. In figs. 124 and 125 EX C is the exciting or field-coil, and A C one of the armature coils.

Excitation.—All these different forms of alternators require separate excitation for their field magnets, with

[1] Brush Company.

the exception of type *d*, in which case a portion of the current generated is sometimes commutated and used for excitation. Separate excitation is effected in various ways, as follows :—

(*a*) *Separate Exciters.*—In this case each alternator is provided with a separate exciter, usually driven from the dynamo shaft, either direct coupled or by means of ropes, and is only of sufficient capacity to supply its own alternator. Should an exciter fail, its alternator is of course disabled.

(*b*) *Separate Exciters coupled in parallel.*—A separate exciter is provided for each alternator, as in the last case,

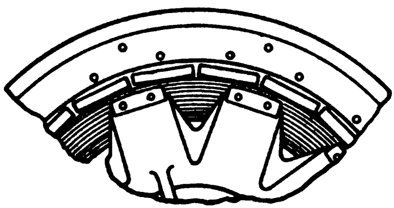


Fig. 124.

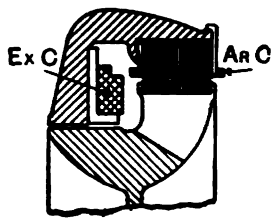


Fig. 125.

but they are all connected together to bus bars, and as each exciter is of greater capacity than is required for one alternator, the risk of disabling the alternators is reduced should one exciter fail.

(*c*) *One large Exciter.*—In this case one large continuous-current dynamo is usually driven by a separate engine, a similar combination being kept in reserve. The capacity of the dynamo is sufficient to excite all the alternators.

(*d*) *Storage Cells.*—Storage cells are sometimes used to excite, either alone or in parallel with either of the above arrangements, and the risk of failure is doubtless minimized by their use.

Exciters are usually of the shunt wound type, although series wound, as well as compound wound, machines have been used.

Parallel Running of Alternators.—When first distribution from a central station by high-tension alternating currents was practised, it was customary to supply each circuit separately from an independent machine, and the opponents of the alternating-current system used as an argument against it that as the machines could not be run successfully in parallel, distribution with such a system on anything like a large scale was quite out of the question, and prophesied the rapid decline of alternating-current practice. It was obvious to all that it would not be possible to continue the arrangement of alternators and circuits then in use, and that parallel running would therefore become a necessity. Although makers of various alternators claimed that they had overcome the difficulty—if a difficulty existed—for some reason the actual systematic running of alternators in parallel did not come into operation for a considerable time, although, for the purpose of changing over from one machine to another, machines were frequently synchronized, connected in parallel, and then separated again. At Bournemouth the Mordey alternators, and at West Brompton the Elwell Parker alternators, were run in parallel as early as 1891, and we believe that these were the first two instances in which it was done systematically. For over twelve months, however, a number of engineers were very sceptical on the point, and asserted the impossibility of its being done successfully, and prophesied all manner of disastrous results; and when at last they were convinced that it was not only possible but had been in successful operation for a year, they still continued to wrangle amongst them-

selves as to the most suitable type of machine, the class of engine, and whether the alternator should be driven by ropes or driven direct in order to obtain the most satisfactory results, and there still exist central stations using alternating-current machinery which have not yet adopted parallel running. That there are greater risks in running alternators in parallel than in running continuous-current machines in the same manner goes without saying; but that those risks are serious is disproved by the fact that it is growing in favour, and is invariably adopted in all modern alternating stations.

In order to obtain the best results and to prevent a "drive" on the machines, with a consequent excessive interchange of current between them, certain obvious conditions are necessary, for example:

(*a*) The turning moment of the engines should be even, particularly when coupled direct to the alternators.

(*b*) The governors should be capable of slight adjustment when running. It is the practice of some engineers to cut out the governors while running in parallel, and to regulate from the stop-valve, but this should be unnecessary.

(*c*) The field of the exciter should be strong enough to resist the armature reaction of the alternator.

Where high periodicities are adopted, it is probably advantageous to run the alternators at a high rate of speed coupled direct to high-speed engines, as if they are coupled direct to low-speed engines the number of poles becomes excessive, and consequently they have to be very small and mechanically imperfect. Slow speed and low periodicity should naturally go together, while, on the other hand, if a low periodicity is adopted and high speed, the mechanical stability is frequently increased. In modern stations low periodicities are usually adopted.

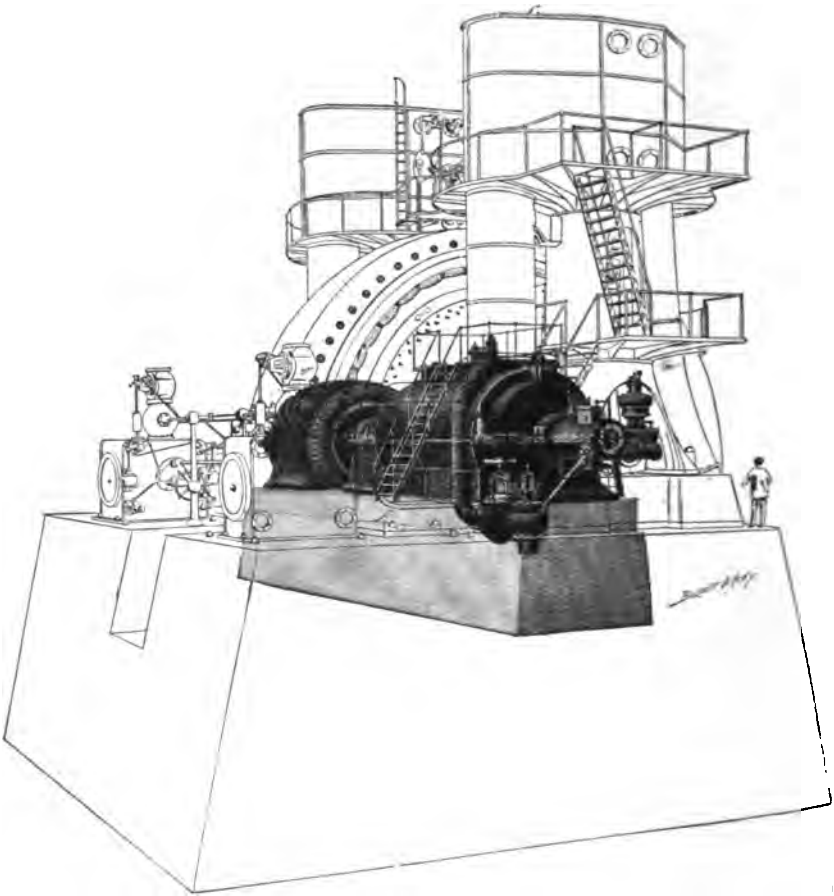


Fig. 125A.—Comparison between Turbo-Generators and Medium Speed Cross-Coupled Engine Sets.

[*To face p. 275.*

When a number of machines whose co-efficient of self-induction is very low are running in parallel, and a short circuit occurs on the bus bars, or in the armature of one of the alternators, the rush of current is so great as to throw a dangerous strain on the armatures of all the other machines, although the fuse of the faulty machine should immediately blow. Where the co-efficient of self-induction is very high the risk is not so great, the increase in current being comparatively slight.

Number and Size of Dynamos.—To decide upon the number and size of dynamos to be fixed in the initial stage of a new undertaking, having regard to future extensions, is by no means as easy as may at first appear, the probable immediate and future demand for energy being difficult to estimate. If there is any reasonable prospect of a fair demand, very small units of plant should be avoided, and, except in small provincial towns, probably nothing less than 100 kilowatt units would be of much use in a year or two after starting.

The question of reserve plant must also be considered in deciding upon the size and number of units. Suppose two 200 kilowatt machines are selected; it is evident that one must be held in reserve, and this represents 50 per cent. of the total plant, while if four 100 kilowatt units were fixed, although more costly, three would be available for work and one for reserve, or only 25 per cent. of the total. Taking the case of the two 200 kilowatt sets again, suppose the first extension is another similar set, the reserve is still 33 per cent., and it cannot be reduced to 25 per cent. until four similar sets are erected. If the two 200 kilowatt sets are augmented by the addition of one 400 kilowatt set, the case is made worse than if one 200 kilowatt set were added, and the original reserve of

50 per cent. still remains, the 400 kilowatt set having only released one of 200 kilowatts. A reserve, equal in capacity to the largest set in the station, is obviously necessary, and if it is desired to reduce the reserve to 25 per cent., there is no alternative but to continue adding similar sets until four are erected. After which, unless the same size is continued; the reserve must increase until again four sets of the larger size are fixed, and so on. When a battery is used the case is similar, and it does not appear that any advantage is gained towards keeping down the reserve, the battery being looked upon as another set in this connection.

Day Plant.—Sometimes a small engine and dynamo are provided to supply energy when the demand is small, as is frequently the case during the daytime and—when street lighting is not adopted—during the small hours of the morning; and there is much to be said in its favour, as the wear and tear on a large engine running light for a number of hours is often excessive. Whether or not the coal bill is seriously affected will depend upon local conditions.

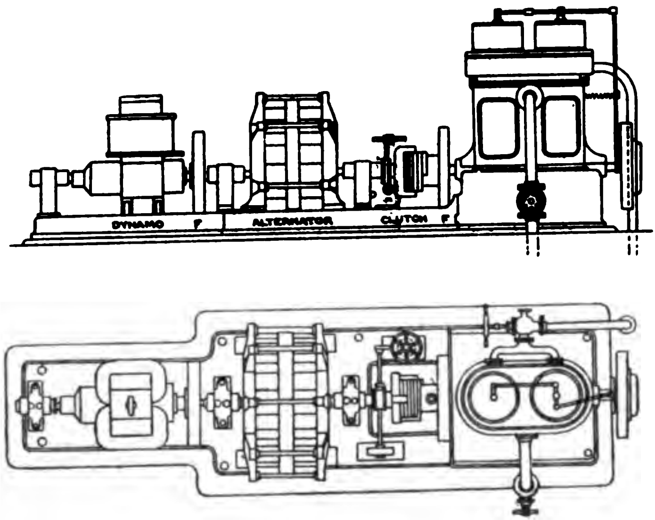
If the main steam-pipe system can be shut down and the day plant supplied through a small separate pipe, the radiation is considerably reduced, but many engineers deem it unwise to subject the pipes to such extremes of temperature every day, on account of the risk, not only to the joints, but to the pipes themselves.

It would appear that, at any rate in a continuous-current station, a battery is here a distinct advantage, as the running machinery can charge up the cells before and after the peak of the load, and so flatten out the load curve. When the load has gone off sufficiently, the battery can be left to do the work during the early

morning and possibly the following day, thus saving labour.

This is usually done only in comparatively small stations or before the demand has become large, after which the battery is used for regulating only.

In some alternating stations, batteries are used in conjunction with a combined plant consisting of a continuous-



Figs. 126 and 127.

current dynamo coupled to a small alternator. Before and after the peak of the load, the alternator is run as a motor and drives the dynamo which charges the battery. When required, the battery drives the dynamo as a motor which drives the alternator and supplies the mains.

Figs. 126 and 127 show a combined plant suitable for this purpose, but with an engine in addition. The set consists of a high-speed engine coupled by means of a clutch to an

alternator, which is again coupled direct to a dynamo. By throwing out the clutch the engine is uncoupled, and the plant can then be used as above described. When the engine is coupled, the set can be used as a day plant complete, as an auxiliary exciter, for charging batteries, and other purposes. It will be seen that even when its usefulness as a day plant has ceased, on account of the demand having grown beyond its capacity, it is still useful in other ways.

Storage Batteries.[1]—It was urged against electric lighting, when first it was introduced, that it could never compete with gas as long as it depended upon continuous running machinery for its production, on account of the unreliability of moving plant, and that until electrical energy could be stored somewhat in the same manner that gas is stored in gasholders, a public supply from a centre would be too uncertain to be successfully continued. The value of this prophecy can be judged in the light of present conditions. When, in 1881, the Faure accumulator was introduced, the problem was said to have been solved. A cell having been charged in London and sent to Glasgow, was stated to contain a million foot-pounds of stored energy, and the usual newspaper paragraphs of the ultra-sensational type appeared daily. In spite of all that has been said in favour of storage, it is the exception rather than the rule to find storage on anything like a large scale in a central station, and the one company who depended entirely upon storage for supplying its customers has since changed its system.[2] Storage, like everything else electrical, has been the subject of much controversy,

[1] Consult Sir David Salomons "Accumulators" (Specialist' Series).

[2] The Cadogan (now the Chelsea) Company.

and while its warmest supporters consider no station complete without it, some of its opponents consider it useless. Storage cells may be divided into two general types:

(*a*) The Planté type.

(*b*) The Faure type.

Briefly, the Planté cell (*a*) consists in its simplest form of two plates of metallic lead immersed in dilute sulphuric acid. The plates are charged and discharged repeatedly, until they are completely "formed," and a layer of lead peroxide of sufficient thickness has been produced on the positive plate.

In the Faure cell (*b*) the lead plates are perforated or in the form of a grid; the holes in the positive plate are filled with a paste of lead oxide, and those in the negative plate with litharge. On charging, the oxide is changed to peroxide on the positive and the litharge to metallic "spongy" lead on the negative.

In both cases the pressure per cell is about two volts, and a number of cells are joined in series until the required pressure is obtained. The capacity depends upon the area of the plates, but for convenience and mechanical stability a number of comparatively small plates in parallel are used, the result being the same.

The size of cell used will, of course, depend upon the purpose for which it is required. They are made in various sizes up to a capacity of 5,000 ampère-hours or more.

Batteries are used in central stations for various purposes, the most important being the following:—

(*a*) To take the peak of the load.

(*b*) As regulators.

(*c*) To relieve the running machinery during hours of light load.

(*d*) As compensators with a multiple-wire system.

(*e*) For sub-station supply.

(They are rarely, if ever, used in a central station as a gasholder is used in a gasworks.)

In stations where the peak of the load (*a*) only lasts an hour or two, those who favour storage claim that a battery is an advantage, as less running plant is required; while others state that an engine and dynamo would cost less for the same capacity, and is more efficient.

In order to prevent fluctuations in pressure (*b*) due to unsteady machinery or other causes, batteries have been found very useful.

(*c*) This has been dealt with under the head of "Day plant."

(*d*) The use of batteries as compensators has been considered in Chapter V., and (*e*) likewise in Chapter VI.

CHAPTER IX

SWITCH GEAR AND REGULATING APPLIANCES

The Object of a Switchboard in a generating station is to form a connecting link between the dynamos or alternators and the feeders or outgoing mains. It is essentially the electrical centre at which the current is measured, the pressure adjusted, the load on the different generating machines regulated, and where the various operations of switching on and off the mains, paralleling machines, and metering the energy generated, are performed. The whole output of a system is concentrated at and controlled by the switch-gear. Appliances should be included for automatically disconnecting any part of the system which may become defective or upon which a fault may arise.

In most stations the switchboard is situated at some convenient spot to which the cables from the generators, regulators, resistances, and mains are brought. When this is done one or more switchmen are placed in control of the regulating, and they have before them all the necessary apparatus. This may be called the centralization principle, and as it has been proved in practice to be a very satisfactory one, it is that now generally adopted in smaller stations.

Some engineers preferred to place the switches for the generators close to the machines they controlled. The

object in view was to enable the attendant to ascertain the condition of the plant at the same time that its electrical power was observed, and he had at hand the stop-valves, drains, handles or levers for adjusting the expansion-valves, &c., of an engine while he was within reach of the switches belonging to the generator it was driving. Theoretically, such a plan should work satisfactorily, but the conditions under which an electricity works is operated do not favour decentralization. Nothing tends to simplify matters or to assist those in charge to do the right thing at the right time more than to have all the electrical apparatus before them, so that by a glance the various pressures, currents and position of switches can be mentally recorded. Changes in number or size of machines at work are then readily made, and the effect of any abnormal occurrence either inside the works or on the mains can be grasped, and immediate steps taken to prevent untoward results.

With the extra high pressures now employed in transmission on bulk supply schemes, and the large generating units, the switchboard would become unwieldy if the gear were concentrated so that the various parts could be directly manipulated on the board. The switches require a considerable amount of space, and this is increased by the necessity of separating them by fireproof partitions. As in so many other sections of electrical work, a compromise must be effected, and the result has been a process of evolution combining centralization of the control of the switch gear, and decentralization of the portions which actually make and break the circuit. This involves a subsidiary arrangement connecting the handles or control parts with the blades or active parts, much in the same way that on large steam-ships the steering wheel merely

controls the steering-engine in its movements, the work of moving the tiller and turning the rudder being performed, not by the steersman, but by the steering engine.

Communication of Orders from the engineer in charge of the switchboard to the workmen, greasers and others in the station presents no difficulty in small works, as the drivers at the engine stop-valves can be given verbal instructions. In large works, where the plant covers a good area, when the majority of the generating units are running the noise and distance combine to prevent spoken orders being transmitted with satisfaction and certainty, and means have to be provided for conveying instructions without confusion or liability to misinterpretation.

The simplest and best for medium-sized plants is a clear-toned mouth whistle which can be blown by the switchman to call attention, a conventional code of hand-signals being then used to indicate exactly what is to be performed. An advance upon this is to fit a couple of diversely-coloured glow-lamps on each engine. Semaphores and ships' telegraphs are also employed, the pointer indicates the instruction, and some auxiliary means is taken to show to what plant it applies.

The most convenient of all devices is at the same time one of the simplest. On the wall of the engine-room a frame is fixed, having twice as many glass panels as there are engines. In the top row the glasses are black grounds with clear numbers, on the lower row the numbers are black with red ground. Behind each glass are a couple of incandescent lamps in parallel, connected to a small tumbler switch on the main switchboard. Lighting up a top number intimates that the engine is to be run up or raised in speed, illuminating the lower number means diminution in speed.

Main Switches must be capable of being operated safely at all times; of carrying the maximum current ever likely to be put through it without undue heating; of breaking this current without dangerous or sustained arcing, they should be substantial enough to withstand the wear and tear of regular service; and all current-carrying parts should be properly insulated (having regard to the pressure at which the supply is generated or distributed), while it is desirable that the "on" and "off" positions should be distinctively indicated, and that there be no chance of unintentional alteration of position.

The three principal elemental forms of switch are (*a*) the lever, (*b*) the knife, and (*c*) the plug. To these may be added (*d*) sliding switches as a fourth class. The lever switch consists of an arm pivoted at the middle or at one end, which is moved to right or to left in a plane parallel to that of the board. The knife pattern, which is closely allied to the lever class, is provided with an insulating arm or plate, bearing conducting parts attached to or carried upon it, which is moved to and fro at right angles to the board. In the plug arrangement there are certain fixed contacts on the board, and these are connected together by the insertion of a separate part comprising an insulated handle, plate or bar, and metallic wedges or plugs, with strips of metal to connect them together. Flexible conducting cords with plugs are occasionally used, and are known as "jack-cords." The general principles of switch-action in the smaller sizes have already been fully treated, so it is unnecessary to devote space to such matters here.[1]

Lever Switches.—This is one of the oldest forms, and

[1] Maycock's "Electric Light and Power Distribution," vol. ii., published by Whittaker & Co.

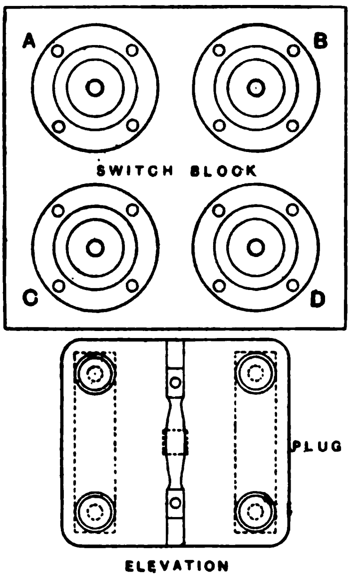
both high and low pressure switches were made on the lever principle almost exclusively for many years. Examples are to be found on low-tension switchboards, while small switches on this principle are used for h.-t. alternating. So long as the pivot is not relied upon to carry current, and the bar is made up of many laminæ, so that each takes its own bedding on the contact plates, these switches work satisfactorily. Heavy-current lever switches are now being made, but the general forms are so well known that it seems needless to illustrate such articles.

The objection to lever switches is the space they occupy on the board. As will be seen, the tendency is now to make everything as narrow as possible, and arrange for any motion to take place at right angles to the board.

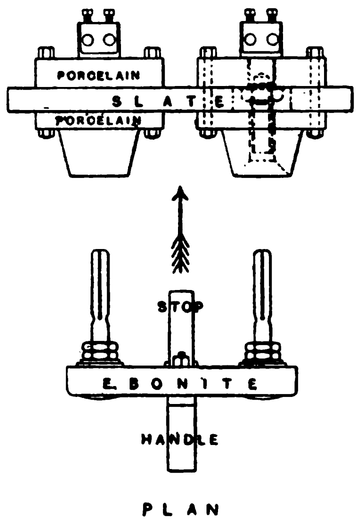
Knife Switches.—Most of the switches on low-pressure boards are of this type. Ample surface can be insured by interleaving the fixed contact and blade, making a large switch the equivalent of a number of small ones in parallel. Up to 7,000 ampères at 220 volts has been carried by a single switch without heating. The concentration of apparatus has probably brought this type forward, as 5½-inch centres have been found to be quite sufficient to allow of instruments, switches, &c., being got in for the control of up to 400-kilowatt dynamos. A view of low-tension knife switches is given in the diagram of a low-tension board later in this chapter, from which the general construction can be grasped.

Plug Switches.—In this pattern fixed sockets are provided on the board, and these are connected together by the insertion of a plug-piece. The break is entirely dependent on the operator. In low pressure gear plugs are used to connect two bus bars, generally with one bar in

front and the other behind the panel of the board. In the Lowrie Hall form for high pressures a slate base carries four porcelain blocks in the centre apertures of which the sockets are hidden. At the back the sockets are connected to terminals for the conductors. Split plugs fitting the sockets are mounted on an ebonite



Figs. 128 and 129.



Figs. 130 and 131.

slab, provided with handle and stop-piece to prevent the plug being pushed too far in. Each switch is composed of a panel with four sockets, two of one polarity and two of another, the upper two (A and B) in fig. 128 being, say, inner and outer bus bars and the two lower (C and D) the respective poles of circuit or machine, and a plug with metallic parts capable of connecting like poles together.

Figs. 130 and 131 give a plan of the switch, which is now obsolete, but is typical of its class.

Figs. 132 and 133 show a typical example of a switch which is a hybrid, being partly of the plug and partly

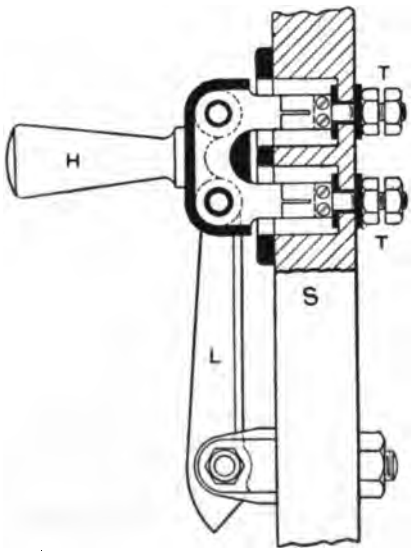


Fig. 132.

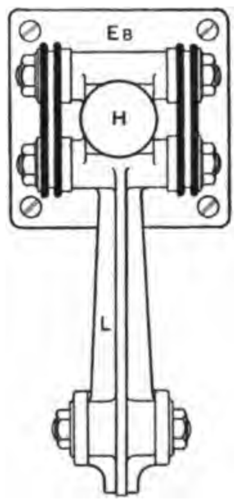


Fig. 133.

of the knife pattern. The parts are insulated by ebonite (EB) and mounted on slate (S).

Sliding Switches.—Where a circuit has not merely to to be made or broken, but a transposition of connection is required, the number of contacts and parts necessitates a long range of motion, and then sliding switches are employed.

Mercury Contact Switches.—Mercury cup contacts in combination with rocking levers, stirrups, and coupling

bars were embodied in many of the earlier designs for central-station switch gear.

The obvious practical objections to a fluid contact,[1] which are best realized by those who have had such apparatus in use for an extended period, have led to surface-to-surface metallic contacts being provided, particularly where the circuit is made and broken repeatedly.

Suppression of Sparking.—On rupturing a circuit when current is flowing the device employed is liable to suffer, due to the spark or arc at the contacts as they leave one another. It is customary to provide renewal spark-taking parts on all switches likely to be used when large currents are flowing.

Elihu Thomson has proposed to insert between the separate blocks of a multiple contact switch choking coils, so that under ordinary circumstances little or no impedance is offered to the current, but on breaking only a proportion is allowed to traverse each contact. This suggestion was first made by Ayrton and Perry, who devised a "non-sparking key" on the same principle many years ago. Another means sometimes adopted is to connect a fine fuse in parallel with a switch, so that the spark is transferred from the switch contacts to the fuse, which may be long enough to open the circuit with certainty.

It is usual to provide a resistance across the switch when opening a highly inductive circuit, so that the induced discharge may have a path in which to expend itself. This auxiliary circuit can be opened afterwards without fear if the resistance has been suitably chosen.

[1] Heating due to dust-films, flashing, and vaporization at break, creeping of the mercury, and amalgamation of the metal throughout are probably most important.

To gradually put on or take off a circuit on an alternating supply a transformer may be used: the primary is inserted in the line with secondary shorted; by increasing the resistance in the secondary the current can be cut down to zero.

Fuses are inserted between the station bus bars and outgoing feeders for the purpose of automatically disconnecting a faulty feeder. Some engineers also insert fuses in the generator circuits, with the intention of limiting the current that can be taken from or returned to a machine; but some divergence of opinion exists as to the desirability of inserting a weak link between a generator and the bus bars, it being argued that a machine should always remain connected, as the load that may be put upon it is limited by the maximum power of the prime mover to which it is coupled.

If a generator breaks down, an excessive current returns from the bus bars into the armature, and unless this backflow can be restricted, unnecessary damage may be done and a serious interruption of the supply must result, as the other machines are overloaded, and their power is turned into their faulty neighbour instead of being sent out to the circuits. It is evident, however, that what is required is an apparatus that acts on reversal of the current and is not dependent for its operation upon the heating effect; the sense of the flow of power is the determining factor, and not the magnitude thereof. Non-return devices have therefore been devised, and have largely displaced fuses as protective appliances for generating machines. Fuses, however, remain still the most suitable means of guarding against overloads on mains, cables and circuits.

The points to be noted in the action of fuses are—

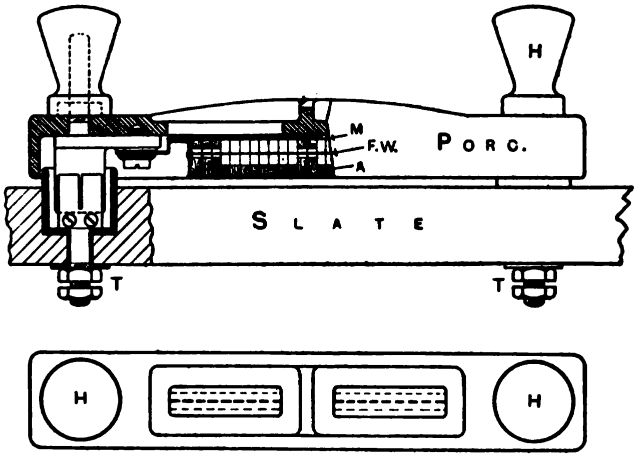
(*a*) that the circuit is broken when an abnormal current is flowing; a fuse differs from a switch, inasmuch as the latter is generally used to open or close a circuit at a time when either no current or only a small current will flow, while the former has the onerous duty of breaking an excessive current; (*b*) that the epoch at which opening occurs depends upon which of the three processes—softening, melting, or volatilization—has taken place. The initial temperature of the fuse is of importance, as the nearer this is to the melting-point of the material the quicker will the fuse go. Much may be learned from the way a fuse "goes." If the whole is dissipated with a disruptive action and loud report and a more or less persistent arc following, a "blow" has occurred and a short circuit is the cause. If, on the other hand, the metal is only gone in the middle and beaded on the ends, then it is merely a "melt," and is attributable to but a slight increase of current, and may be traced to overloading or defective design or condition as well as to fulfilling its object. (*c*) That the gap bridged by the fuse is filled with metallic vapour at the time of action. This, perhaps, is the most vital matter in connection with large fuses for high pressures, and the greatest success has been achieved by making efforts to get rid of the metallic vapour as quickly as possible, or by interposing a screen, shutter, or insulating liquid between the contacts when the fuse gives way.[1]

The methods adopted to devise non-arcing fuses are many, but the most successful are:—

1. Using metals whose vapour is not capable of sustain-

[1] A detailed account of the action of fuses will be found in the first edition of this work.

ing an arc.[1] Pure block tin rolled out into thin sheets makes a satisfactory fuse material for moderate pressures and currents.[2] Lead, lead-tin alloy, and similar mixtures are sometimes used, but tinned copper wire is probably unsurpassed for currents up to 300 or 400 ampères. A



Figs. 134 and 135.—Cowan and Still's type of h.t. fuse.

number of wires, say six to twenty, put in parallel and carefully graded, are as reliable as anything we know.

2. Interposing large masses of refractory material about the path of the arc, to cool the air and condense metallic vapour.

As example the Cowan-Still pattern in which the wire passes through a chamber formed of asbestos pieces laid side by side, and retained in place by strips of mica. The frame is refitted after being removed from the base

[1] Consult Weston's experiments on non-arcing metals.

[2] Hedge's mica-foil fuses of some years back showed an appreciation of the requirements of fuses that is not always found even to-day.

block, so that no risk has to be taken by the attendant in replacing a burnt-up fuse.

3. Arranging bridges of insulating and refractory material through which the fuse conductor passes in minute holes, not large enough to permit the arc to follow. If a glass tube be filled with a dust or sand mixture the particles of non-combustible insulating matter close up the path of the arc, and damp it out. Fig. 136 shows one

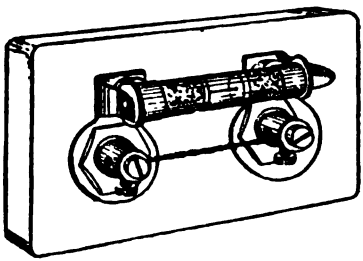


Fig. 136.

form,[1] in which the amount of air in the tube is reduced, and part of the space it occupied is taken up by a highly resisting medium in the form of powder.

4. Interposing a non-combustible shutter between the contacts at the time the fuse meets.

The Peard fuse is one of the type in which an insulating partition is forced by springs between the terminals on the fuse-strip meeting. The Partridge high-tension fuse is fitted with small closed vessels containing compressed carbonic acid gas (sparklets) and on the arc taking place in their immediate neighbourhood these are ruptured and the escaping gas blows out the arc.

5. Placing the fuse in a magnetic field so that the movable conductor formed by the arc is repelled outwards

[1] W. M. Mordey. Patent No. 19076, November 24th, 1890.

and broken up. The magnetic blow-out principle has been embodied in low-pressure fuses, and it is claimed to be the only known method of preventing destructive arcing. It is not considered necessary in this country to take special measures of this sort with fuses on lighting circuits, and the feeders on continuous-current boards generally have open foil or strip fuses; but with inductive circuits on which motors, &c., run, some provision has to be made to cope with the vicious arc produced by the induced discharge, and maximum current cut-outs are then preferable.

6. Making the heat of the disruption induce a current of air to blow out the arc.

The Bates fuse consists of a base carrying two fixed contacts. As will be seen from fig. 137,[1] these pillars are

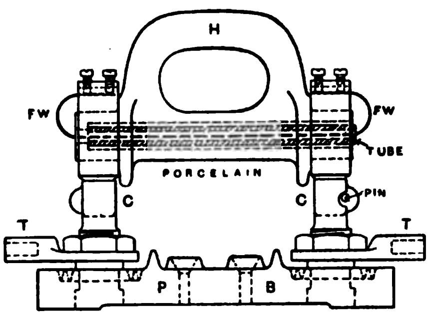


Fig. 137.

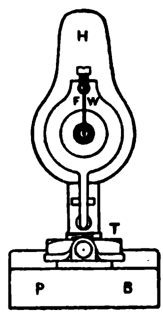


Fig. 138.

slotted to take the plugs of the removable fuse block. The fuse block is formed in the shape of a handle-bar, with a circular aperture longitudinally through it, and the contact pieces on its ends. One of the contact pieces has a pin set through it at right angles, to act as a hinge when

[1] Another pattern of more elaborate design is also now made.

inserting or removing the fuse. The small set screws on the end blocks grip the fuse wire, which is threaded from one end of the handle to the other through the aperture, in which is first placed a length of fire-clay tube or piece of tobacco-pipe stem. When the fuse wire blows, the heat evolved causes a rush of air through the aperture, which blows out the arc. Owing to this action the length of break is less than would otherwise be necessary. From the shape of the removable part, this fuse can be used as a switch as well. By keeping handles wired ready for use a melted fuse can be replaced in a few seconds. A fine wire, threaded through a rubber tube has been used, and it is stated that this has never been found to fail in breaking the circuit, as the arc is blown out, and the elastic nature of the tube assists the air blast by dividing the space up into sections.

7. Quenching the arc by covering the contacts with insulating oil of high flash-point at time of melting.

With the object of reducing the dimensions of high-tension fuses and to make their action certain, while at the same time destructive arcing is guarded against, Ferranti has introduced oil-pot fuses in which the fuse wire is kept under tension by a pair of springs, and when these are released by the softening or melting of the fuse link they fly off, immersing their whole length in an oil bath. This effectually quenches the break spark and causes the circuit to be opened immediately.

The dynamo or main-feeder fuse of this pattern is of a type represented in figs. 139 and 140, one quarter real size (lineal). A moulded stoneware double trough is provided with a handle and cover, and is fitted on the outside, at the back end, with two large contact plugs of copper for making connection with fixed fuse contacts. The current flows

from one plug to the fuse by a flexible copper connection in parallel with the steel spring which is used to keep the fuse wire in tension. The two halves of the pot are similar. The fuse itself consists of a number of fine

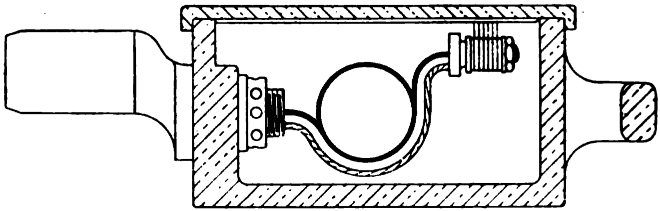


Fig. 139.

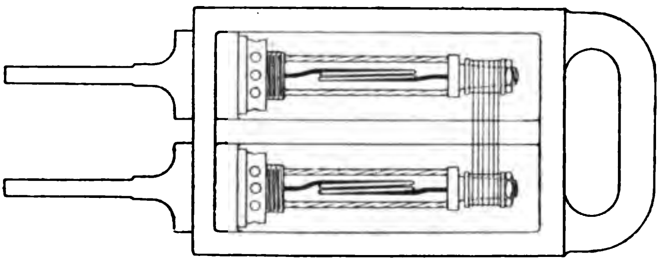
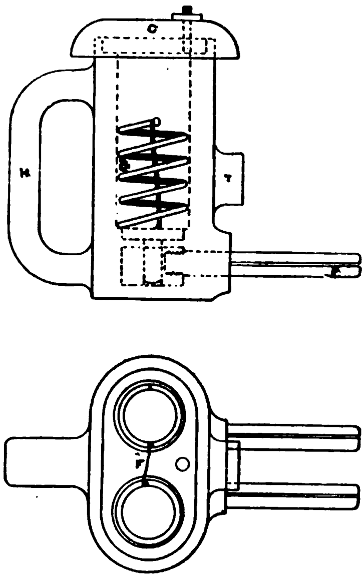


Fig. 140.

tinned-copper wires (say 24 to 30 S.W.G.), laid up in parallel on two brass sockets which are slipped on the coned ends of fixed plugs carried by the ends of the steel springs. These wires lie across the bridge between the two troughs, and are secured in position and good contact ensured by a thin line of solder being run along each socket over the wires in a direction parallel with the axis, and the sockets are fastened on the plugs by a brass nut, as shown in the drawing. The fuse itself is about 1½ in. long when intact, but immediately on its fusing the break is increased under the action of the springs, and the whole

of the contacts become submerged in the oil bath. Figs. 141 and 142 show the form of this fuse designed for small currents. Fuses of this pattern are used on the small rectifier boards, and when fitted with vertical plugs are convenient for street box fuses.

High-tension Fuses are made in a number of different



Figs. 141 and 142.

patterns, depending upon the pressure of generation, the space available, and considered necessary to prevent destructive arcing. The important characteristics of such a device are:—1. Absolute safety to the attendants. 2. Good insulation. 3. Proper means for breaking the circuit.

The safety of the staff is secured by the fuse when in

use being protected from accidental contact with the person or with adjacent part belonging to or apparatus on the switchboard. The fuse wire should be always in view, so that its condition may be inspected from time to time without inconvenience. The fuse should be of such a pattern that when the wire "blows" or melts, the attendant standing near or below does not receive a shower-bath of molten metal. All material round a high-tension fuse should be non-combustible and substantial. The insulation from earth should be practically perfect, and so should that from one side of the circuit to the other. This can only be attained by the use of porcelain and slate. Slate alone is not sufficiently insulating, but by mounting all metal-work on porcelain and carrying the porcelain insulators on a slate base, good insulation is maintained and a mechanical job ensured.

Duplicate Fuses are desirable where the peak load on a feeder is considerable, and the fuses are therefore heavy; during the day lighter fuses should be substituted for those employed during the time when the output is large. It does away with the possibility of a large and destructive arc forming at a fault which may come on when the current is small and when the margin allowed in the fuse is very great. Several h.t. switchboards are fitted for this purpose with duplicate fuses that can be put in parallel with one another and changed without opening the circuit. This also permits the working fuse to be withdrawn for examination, and prevents the possibility of any damage being done to the generator or the external circuits if a short occurs when the examination is being made. An older device was to arrange a shorting plug across the fuse with the same object, but this is liable to abuse.

Although, perhaps, in low-tension supply the necessity for duplicate fuses is not always manifest, there is an advantage in always having a spare fuse ready, and it is sometimes the practice to arrange a pair of fuses side by side, either one or the other being brought into circuit by the insertion of a plug into appropriate sockets.

It is obvious that with shunt-wound continuous-current machines fuses are not essential, as a short circuit destroys the field of the machine very rapidly. With tunnel-wound or iron-cored alternators the inductance of the armature winding is usually sufficient to prevent a dangerously large current on a short circuit.

Non-return Devices are automatic switches acting only on a reversal in the direction of the current. They were first employed to safeguard secondary batteries when being charged by continuous-current plant.[1]

The three classes into which the different forms now used for machine and circuit protection may be divided are: firstly, those depending upon polarity of an electro-magnet; secondly, zero cut-off devices which let go a switch and open the circuit when the current falls below a certain predetermined value on the down grade to reversal. The latter are simpler than the others, and may usually be adapted for use with alternating current by merely laminating the iron core and otherwise guarding against the formation of eddy currents. A continuous-current 1,500 ampère non-return device of the second class is shown in figs. 143 and 144. The current passes through the fuse and solenoid to the double-break switch and terminal T_2. The coiled springs tend to throw the pivoted switch lever off. A catch holds the lever on

[1] e.g. Holmes, Crawley, Williamson, Dorman, and others have designed patterns.

until the circuit is made, and then the catch is released and the magnetic attraction keeps the switch closed until the current falls, when the springs cause the lever to fly off and open the circuit. Thirdly, there are some devices which not only switch off, but also automatically switch on.

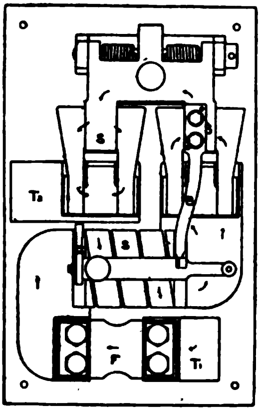


Fig. 143.

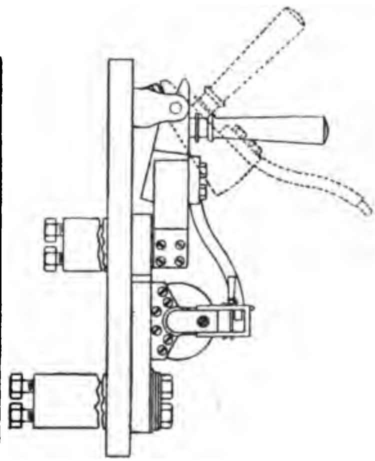


Fig. 144.

Reverse-current circuit breakers should under no conditions cut off a generating machine supplying current, but must immediately disconnect or isolate a faulty generator upon current returning to it from the bus bars. The action should be more rapid with large than with small currents, and it should not fail even if the bus bar pressure is considerably reduced. The last condition is that most difficult to meet, as a differential or compound-wound coil involves the employment of a shunt current, and if this is cut off the apparatus is disabled. The principle of the zero

current simple solenoid form already described is shown in the diagram No. 145. By compound winding, as in fig. 146, the forward current acts in addition to the shunt current to hold the contact lever on, should the main current reverse its magnetic effect, being in opposite sense to the shunt current neutralizes the latter, and the lever falls and opens the circuit. Another form is shown in fig. 147, where the forward main and shunt currents

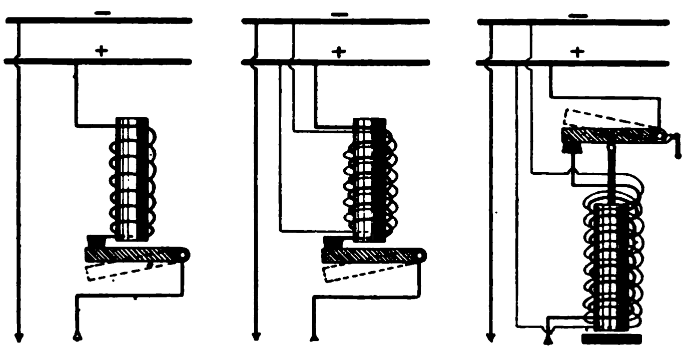


Fig. 145. Fig. 146. Fig. 147.

neutralize one another, but a reversal of the main current causes its magnetic effect to be added to the shunt current, and the core is pulled upwards, lifting the lever, which is caught by the catch, keeping the circuit open. This form has the disadvantage that a heavy forward current will overpower the shunt, and cause the circuit to be opened, a failure in the shunt producing a similar effect. This can be got over by separating the magnetic effects of the shunt and series coils, using a magnetic bridge arrangement, fig. 148. When the series coil is traversed by a forward current, the magnetic flux passes round the ring, the magneto motive forces of the two coils being in series

and short-circuited. Reversing the main current produces salient poles between the projections, in which a core is placed, and this is attracted upwards to close the magnetic circuit tripping the contact lever.

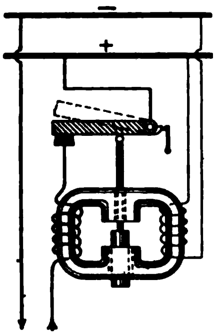


Fig. 148.

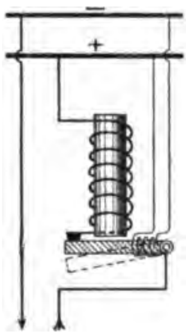


Fig. 149.

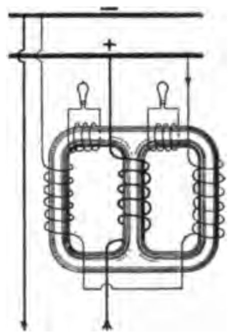


Fig. 150.

The forms described are used on continuous-current circuits; for alternating devices a polarized contact lever is used, as depicted diagrammatically in fig. 149. With a forward main current the series coil magnetized its corc so as to attract the contact lever, on which is wound the shunt coil. For the purpose of operating non-return switches or indicating the direction of an alternating current discriminating transformers on the principle shown in fig. 150 are now largely used. They work on an adaptation of the magnetic bridge, illustrated in fig. 148. The ring core is wound with a pair of shunt coils in series producing consequent poles. On a cross core the series coil is wound and on each side a secondary coil is placed, these either supply current to operate a switch or light a coloured lamp. With a forward current the flux produced by the series coil is added to the flux from the left-hand

shunt coil, and neutralizes that from the right-hand coil, causing the green lamp to light up. A back current sends the flux through the right-hand half of the core, and lights up the red lamp. As the two shunt coils are in series, the action of the apparatus is not interfered with by mutual induction between the series and shunt currents, any effect on one being balanced by an equal and opposite effect on the other. This form of discriminating device has been brought out by Mr. Leonard Andrews, who has designed a number of non-return cut-outs for generating and sub-station use on both continuous and alternating currents.

Instruments on the switchboard usually include ammeters or current gauges, voltmeters or pressure gauges, power or watt meters, coulomb or "unit" meters, leak detectors or fault indicators, balance and power factor indicators, polarity indicators, frequency tellers, and such like.

Ammeters are inserted in the circuit of each generator or battery to show the loading on each generator and to indicate the demand on each part of the district as supplied by the different feeders. They are now almost wholly confined to two types, those in which a solenoidal current sets up a field producing rotational or translational movement of a soft iron core, and forms confined to continuous-current work embodying a fixed permanent magnetic system with a moving coil carrying a fraction of the current to be measured, the instrument being placed across a heavy-current shunt. The instrument should read fairly correctly, have a reasonably good scale, not introduce appreciable resistance into the circuit, and be damped so that the needle does not swing backwards and forwards so much as to render reading difficult. Owing

to the number of ammeters required on a large board, it has been found advantageous to devise forms with vertical scales, narrow and deep in body, so that a number can be got in side by side, edgewise in a small space. This enables the ammeters to be placed above or below the switches of the circuits in which they are connected.

Voltmeters are either similar in construction to ammeters, or else depend upon the heating of a thin wire or the electrostatic attraction between two systems insulated from one another and connected respectively to the two points the pressure between which it is required to measure. Electro-magnetic instruments of the first class are commonly used for purposes where extreme exactness is not a matter of moment. For checking the working instruments in continuous-current stations those of the third class are frequently used, and displace the others on h.t. alternating systems.

The Position of the Switchboard depends upon the ideas of the station designer as to management and the class of apparatus most suitable for the purpose. In the pioneer stations no special provision was made, such appliances as were found to be necessary being put up on the walls or on a light batten framework wherever space permitted. This did not tend to efficient working in after years, and it is only occasionally that this lack of foresight was shown in later designs. If the switches, &c., were placed near their respective machines, a definite position was assigned to them in the original plans and the whole lay out was symmetrical. Either pillars were erected in these positions, or the boards were fixed on the walls. Where this was done, the position chosen was often in the neighbourhood of the steam-valves, and if pillars were put up they had a similar appearance to the valve and gauge

pedestals so frequently used by makers of horizontal engines.

Where the switch gear is now concentrated it may either be placed on the ground floor of the engine-room, on a gallery running round part or the whole of the room, or in a room set apart for the purpose and provided with ready means of access to the machinery.

Where the first disposition is adopted, the board is sometimes raised a foot or two above the level of the engine-room floor by a low brick or concrete pier, enabling the attendant to get a better view of the working of the machinery. This is advisable particularly in high-tension works. By far the most common thing is to find the apparatus placed on a higher level than the engine-room, so that the staff have a coign of vantage from which to control operations. A switch gallery is built partly or wholly round the engine-room, and the persons who have access to this are aware of the risks incurred. Perhaps the best arrangement is to place the switch gallery across the engine-room at one end, or along the side, and to concentrate the controlling gear thereon where a switchman is kept to attend to it. The engineer in charge of a shift can then be left free to generally supervise the running of the plant. The drivers look after the running of the machinery, following the orders they are given from time to time by the assistant on the switchboard.

Forms and Types of Switch Gear may be divided into solid flat, panel flat, separate or multiple box and pillar gear, according to the way they are built up, but the two main classes are open and backless. The means of control or operation may be direct or indirect, and this gives another means of subdivision into types.

Solid boards are occasionally used in low-tension stations; they are designed in the first place to accommodate all the

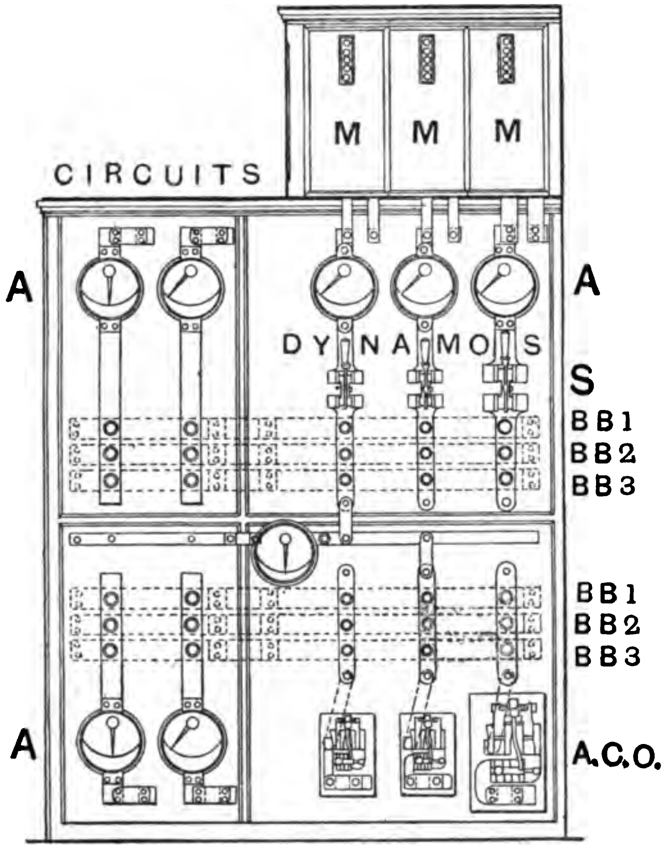


Fig. 151.

gear and instruments likely to be required, and have a foundation of a single slab of slate or marble. Such boards are not readily extensible, and are generally

employed where the apparatus cannot readily be arranged in a uniform or symmetric fashion.

Panel boards are by far the most common type, the switchboard being composed of a number of slate or marble panels mounted on a framework of iron girders and angle iron, timber baulks and battens having been used in the earlier stages, but now avoided owing to their inflammability. A panel is complete in itself, and each of a kind is uniform with others for the same purpose. Thus the board is built up of a certain number of dynamo panels, several circuit or feeder panels, and one or two special ones for synchronizing, exciter, booster, or battery regulation, and the like. Extensions can readily be made by adding the requisite number and kind of panels, without in any way departing from the original arrangement, creating an eyesore or unnecessarily complicating the connections. Fig. 151 shows the front elevation of a three-wire board with meters in one pole, and automatic cut-outs, A.C.O., in the other pole of the generators. A dynamo and a circuit panel are shown, the generator portion of the board being built up of a number of similar panels.

Separate boards, as the name indicates, include all forms in which the component parts of the complete switch gear are distributed and apart from one another. Thus, on the wall near each generator may be fixed the switch and instrument controlling it. This class and the next differ only in the manner of supporting the apparatus. Separate boards are obviously opposed to the principle of centralization.

Pillar gear is occasionally combined with one of the first two forms for special purposes. Thus, the field-regulating switches of a three-wire station may be fixed

on the rails enclosing the switchboard, or mounted on pillars specially made for the purpose. On the other hand, the whole of the apparatus may be arranged on this principle, and it is claimed that by so doing much risk is avoided. Into this class fall the methods which resemble the operation of a railway signal-box, where mechanical connection is made from a pillar or frame to electrical gear some distance away. As a rule, however, solid and panel boards are centralized, and separate and pillar boards decentralized, it being at one time claimed that the advantage of the pillar arrangement was the proximity of all mechanical and electrical gear belonging to each unit of plant.

The greatest risk to which a station building is exposed is fire caused by leaks, short circuits, or open-circuit faults; or by the defective working of some portion of the gear; and the attendants are endangered unless precautions are taken to guard against electrical shock, and burns caused by arcing or sparking. Fire risks are minimized by constructing all parts of non-combustible material, and by doing everything to maintain good insulation throughout. The board should be, as far as possible, its own diagram of connections, having everything as simple and substantial as possible, and all fixings thoroughly sound mechanically. Safety to life requires, in addition, that the attendant should not be able to accidentally touch any metal-work which may be intentionally or accidentally charged to a dangerous pressure.

The Open Flat Type of board stands vertically, having on its front face the switches and instruments, lugs or terminals projecting through the marble or slate slabs enable the various appliances to be connected together. Behind the vertical partition formed by the board itself is

a space in which the cables are run and access can be obtained to examine the connections. The "back" is considered by some engineers to be highly objectionable, others hold that as it enables the whole of the connections to be left open to examination its advantages outweigh its drawbacks. All cable used behind should be covered with a non-inflammable protection, and everything should

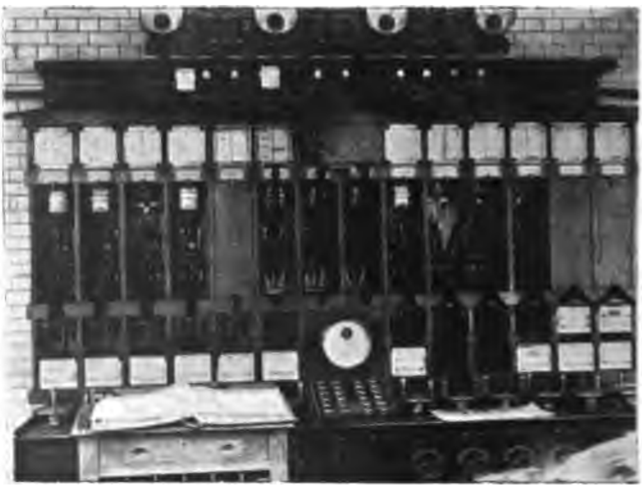


Fig. 152.

be thoroughly insulated and given plenty of clearance. Ample space (at least 4 ft. in width) should be provided at the back of a board which is not fixed against a wall, and this space should be properly lighted. All parts which are not enclosed and access to which is not under lock and key should be securely fenced in, although it is questionable if the backs of boards should be covered with glazed frames: the greatest security is attained by restrict-

ing entrance to those who know the risk and have sufficient intelligence to safeguard themselves against the chance of accident.

The Cellular Construction of high-pressure gear is shown in fig. 152. Each switch, &c., is enclosed above, below, and on both sides by slate shelves and panels, the back of the

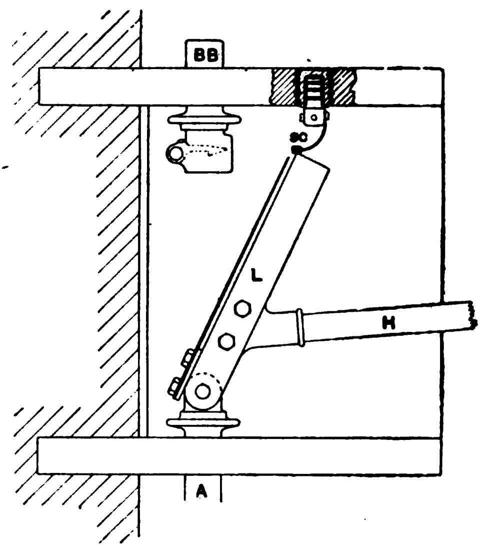


Fig. 153.—Ferranti switch going in; synchronizing position.

compartment being another slate panel. Each cell is, therefore, open only to the front, and can be built up bodily against a wall instead of having an open space behind the board. The Ferranti switches on the smaller sizes have a spring break piece (figs. 153 and 154), and in the larger an auxiliary oil-break with pin and socket, the main lever opens first and the break is made rapidly.

The switches are made single pole or, by linking two together, double pole.[1]

As the lever stands in fig. 153, the alternator is joined up to the synchronizer and represents the first stage in the process of paralleling a machine on to the bus bars. When synchronism has been attained the handle is raised still further, pushing the lever over to the main contact and

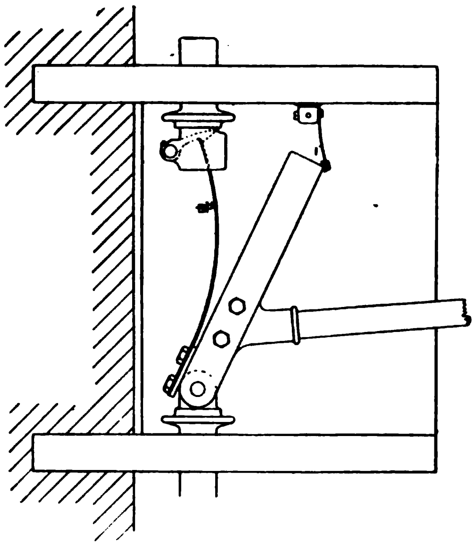


Fig. 154.—Ferranti switch coming out; breaking circuit.

placing the alternator on the bus bars. By this device no separate synchronizing switch is required. The next illustration (fig. 154) gives a view of the switch lever when it has reached the half-way position on breaking the circuit. The back of the contact spring attached to the synchronizing terminal is provided with an insulating

[1] A full description of the various patterns of switch gear is given by Mr. H. W. Clothier.—*Inst. Elec. Engrs.*

piece, so that the circuit with the synchronizing converter is not made on the return movement of the lever. A sparking piece or spring forms part of the lever, and is held by the catch on the top terminal until the handle has moved through a considerable arc. When the spring is released it flies off suddenly, breaking the circuit instantaneously and making it well-nigh impossible for an

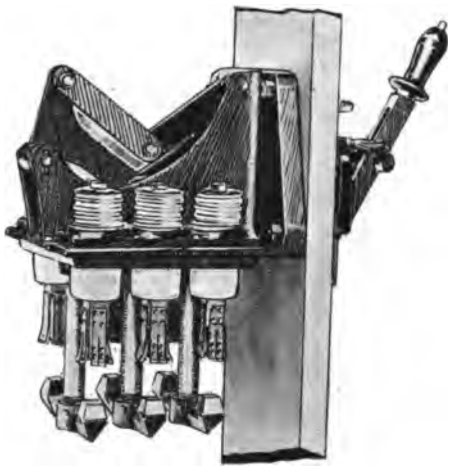


Fig. 155.

arc to carry over or to honeycomb the end of the principal contact lever.

In the largest sizes the contacts are bodily immersed in an oil chamber.

Another pattern of oil-break switch is shown in fig. 155, directly hand-operated, and for heavy work the contacts are separated and the control is electrical as depicted in fig. 156.

Each single pole element is formed of two cylindrical

vessels containing the oil and contacts. Each cylinder is mounted on a porcelain insulator, and these with their cylinders are attached to one sliding platform. Connection is made between the two vessels, forming a single

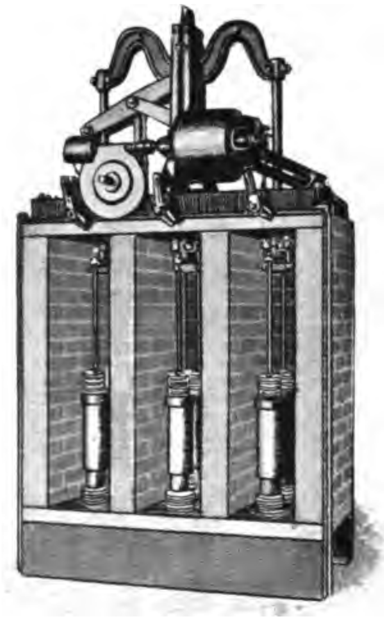
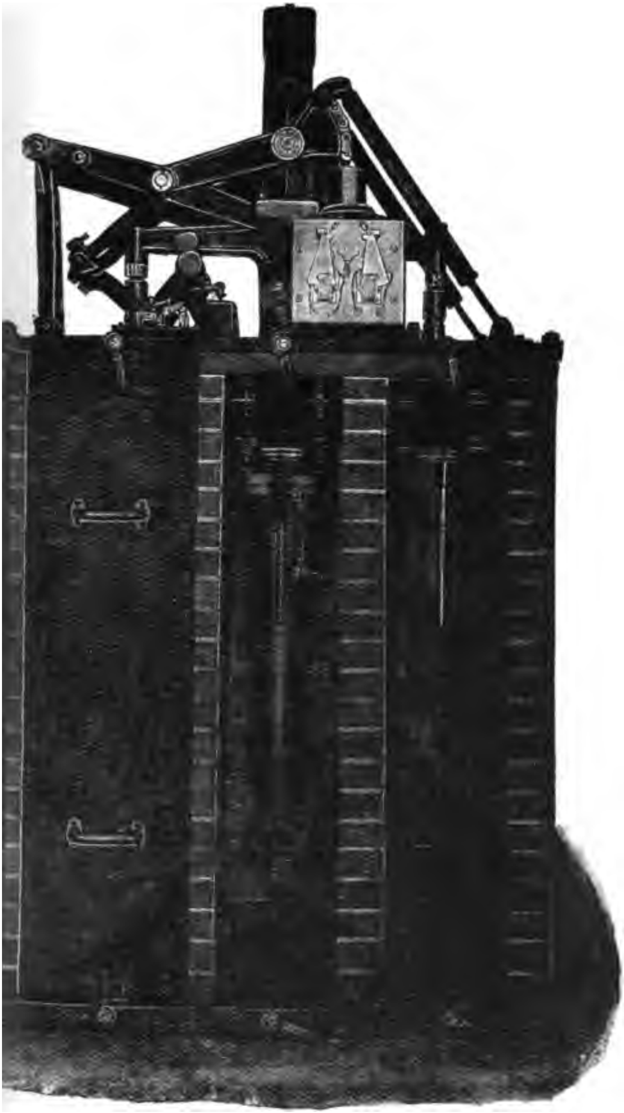


Fig. 156.

pole element, by a U-shaped copper-rod which makes and breaks contact in the oil.

The switch is mounted in a brick compartment with soapstone top and bottom, adjacent poles being separated by a brick partition. It is operated by a motor driving a worm gear, which transmits the motion to a crank and crosshead through a friction clutch. At both ends of the

Figs. 157 and 158.—Type of Extra High Tens



Oil Break Three-Phase Main Switches.

[To face p. 312.

stroke the crosshead compresses a spring which, as soon as the crank passes the centre line, instantly throws the crosshead to an opened or closed position, depending upon whether the switch was at the time opened or closed. The friction clutch permits of this rapid movement, as the pawls hold the disc from moving against the normal direction of rotation while permitting it to move freely in the direction of rotation. The crossheads and contact rods are connected together by wooden rods, which provide for the mechanical movement, and also thoroughly insulate the different poles. The motor is controlled by means of a single-pole double-throw, hand-operated switch, one throw being used to open and the other to close the oil switch, and in addition an automatic switch is mounted on the base. When the hand-operated switch is thrown the motor starts and runs until the crank has arrived at a certain position, when the automatic switch opens the motor circuit and lights a lamp, which informs the switchboard attendant that the switch has operated.

Parallel Running in continuous-current stations is universal. The dynamos are run together on bus bars. As the only condition which has to be observed is that incoming machines are at the same pressure as the bars, the apparatus provided is very simple, and it is the exception to find special provision made for the purpose. Where the board is arranged with a voltmeter on the bus bars and another that may be connected to any machine, all that has to be done is to see that the pressures are equal when the switch of the incoming machine is closed. By giving the engine more steam the dynamo takes up its proportion of the load, and the subsequent regulation may be effected by opening or closing the stop-valve.

As a guide to the proper time for closing the circuit an incandescent lamp—or better a voltmeter—may be connected across the two terminals of the switch, and when the lamp or instrument indicates no current—denoting an equality of pressure on each side of the gap—the switch is made without any risk; a polarized voltmeter being the

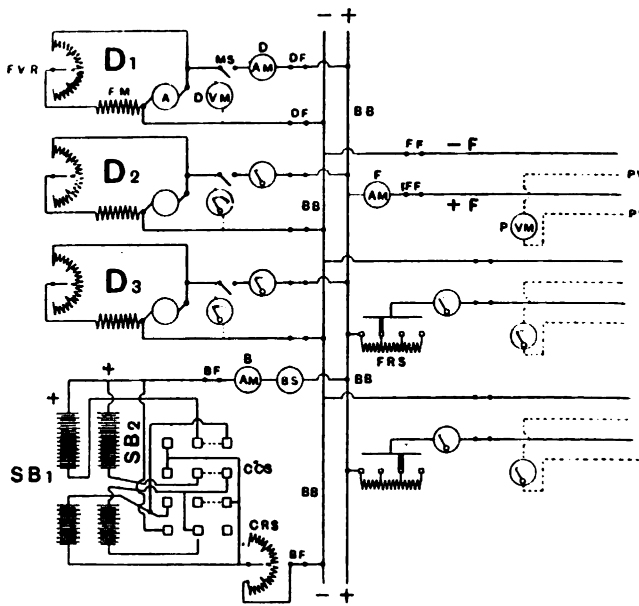


Fig. 159.

most satisfactory form to use in this way. Another method which has been used is to put the dynamo on to the bars through a resistance at first and to fix a sensitive polarity indicator on the ammeter. The direction of the current is then known, and when the current falls to zero the incoming machine is switched in.

Typical arrangement of a switchboard for a two-wire board is diagrammatically depicted in fig. 159, which gives

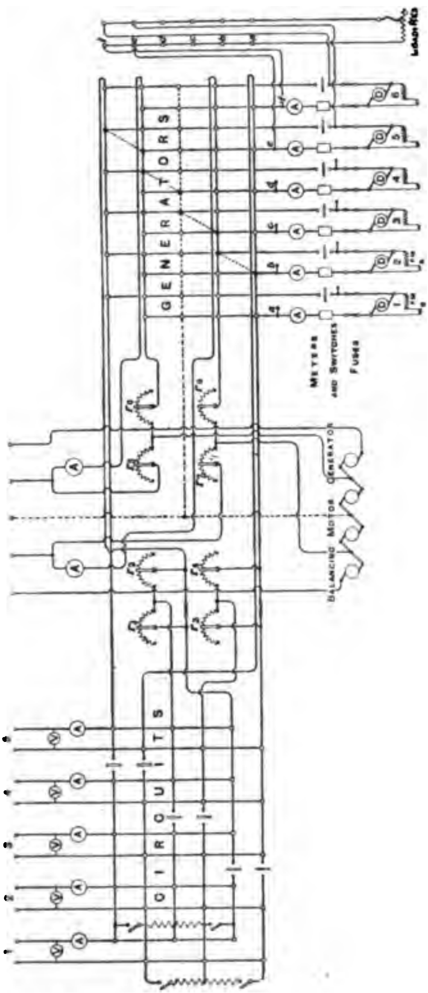


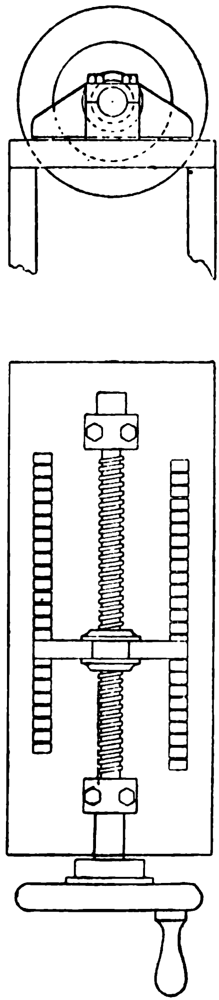
Fig. 160.—Typical arrangement of a five-wire board. The intermediate switches and resistances enable the bus bars to be split up into sections and reconnected as required. The generators are on the right-hand side, the balancing arrangements in the centre, and the feeders on the outers to the left-hand side. The neutral conductor is dotted. Following the diagram from description already given, the use of the various parts can be readily seen. The resistance switches r_1, &c., are used in starting up the motor generator, allowing it to take up its load slowly. The resistances on the extreme left enable the sets of bus bars to be coupled when they are running at slightly different pressures.

the simplest arrangement for three dynamos, D_1, D_2, and D_3, feeding in parallel three feeders, with an auxiliary battery of two sets of cells, SB_1 and SB_2. In this case the batteries are split into three parallels and connected in series with a charging resistance switch for charging, and discharged in two parallels directly on the bus bars BB. The pilot wires PW are brought back from the feeding points, FM is the field magnet of DI_1, and FVR the fixed (regulating) variable resistance; A is the armature, MS the main switch, VM the voltmeter, and AM ammeter for each machine; FRS is a feeder resistance regulating switch or short feeder, DF the dynamo fuses, and FF feeder fuses.

Dynamo Excitation may be separate-exciting, self-exciting, or bus-exciting, and the connection of the dynamo fields to the switch gear vary accordingly. Separate excitation is divisible again into separate single and separate parallel methods, depending upon whether each dynamo has a single exciter to itself, or the whole of the field windings in parallel are supplied from one or more exciters run parallel on bus bars. Continuous-current machines are usually self-excited in small sizes, and bus-excited in large. The advantage of self-excitation is that the field dies down as the machine is stopped, and there is no danger of induced pressures stressing the insulation, while the maintenance of the field is not dependent on any other apparatus or plant. Self-excited machines may, of course, be either "series" or "shunt," according to the conventional designations; but we are here dealing with single-exciting circuit machines, the common type for station work.

A method of field excitation which combines the advantages of self and bus excitation consists in conecting one pole of the dynamo to a change-over switch, enabling this side to be put on the common or auxiliary + or

—bus bar. Each blade has three positions, +, –, and "off." The other pole has the main switch. One terminal of the field winding is permanently joined to one dynamo terminal; the other is joined through the regulating resistance to the blade of the special field switch. On starting the dynamo the field switch is thrown on, and the magnets are at once excited from the bus bars, when the proper pressure is reached, the main switch is closed, and the machine is on the bus bars. On the blade of the main switch are mounted clips, which engage into the blade of the field switch, and a pin, operated by a spring, drops into a hole or slot in the blade of the field switch, securely locking the two switches together. Thus, when the blade of the main switch is opened, it brings the field switch off with it, the two remaining in electrical connection together. On shutting down the engine the field gradually dies down, the machine being self-excited.



Figs. 161 and 162.

Regulating switches for adjusting the resistance in the field circuits of dynamos or exciters may either be multiple contact with a pivoted lever moving round a circular path, movement in one direction increasing and in the other reducing the included resistance, or may be specially designed to save space, and yet not cramp the contacts or limit their number. Figs. 161 and 162 show one form which illustrates the principle.

Synchronizing and Parallel Running with alternators requires that the pressures should be the same on the bus bars and on the incoming machine,

and that the connection should be made when the waves coincide in magnitude, position, and sign; in other words, co-phasal running must have been attained, and the currents on the bars and in the alternator be synchronous. When this condition has been attained, the alternator switch is closed and the incoming machine is then in parallel with those previously running. Instead of coupling directly to the bus bars, some engineers have preferred to connect the incoming

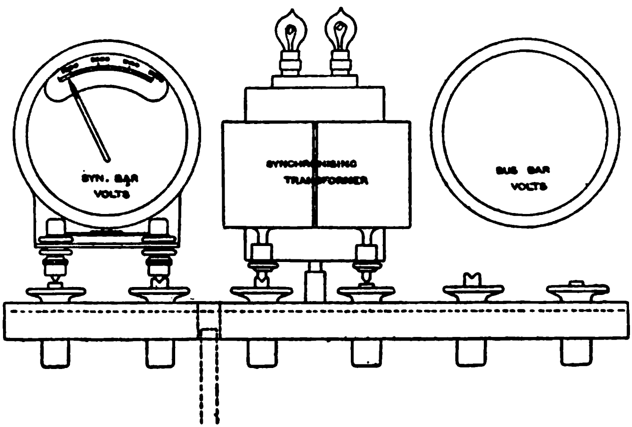


Fig. 163.

machine through a special paralleling switch and fine fuse, and afterwards, when sweet running and absence of "drives" indicated the success of the paralleling, closed the main switch. Others, again, introduced impedance which could be varied, between the incoming machine and the bars, and gradually cut this out, allowing the machine to take up its load slowly.

The Ferranti synchronizing tackle, provided with the switches previously described, is shown in fig. 163, and

consists of two electrostatic, high-tension voltmeters, one on the bus bars, and the other across the incoming machine, with the synchronizing transformer and lamps in the centre. The connections are similar to those hereafter

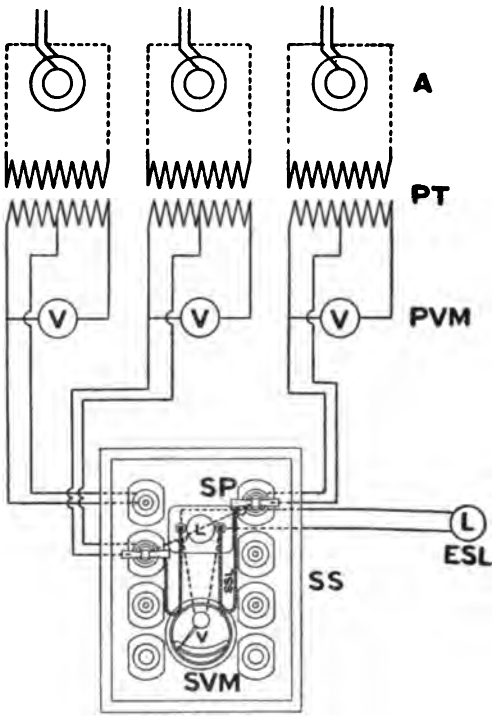


Fig. 164.

described. Hot wire or Cardew voltmeters are very satisfactory for guidance to the switchman in synchronizing, incandescent lamps being employed to indicate to the engine-driver when he has run his engine up to a synchronous speed. Automatic devices for coupling

alternators in parallel have been described at different times, but they have not come into use, and are quite unnecessary.

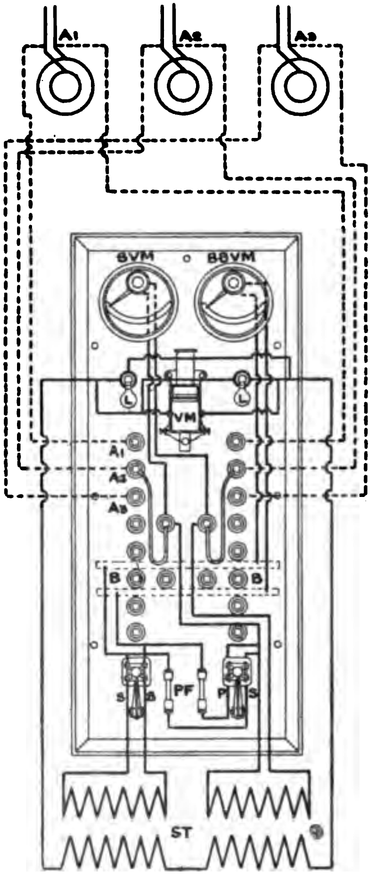


Fig. 165.

There are different ways in which synchronizing gear is connected. In the first (fig. 164), each alternator

has its own pilot transformer, PT, having a transformation ratio of, say, 2000/100, and voltmeter, the primary winding being across the alternator terminals, A, and the secondary coupled to a voltmeter, PVM. From the centre of the secondary coil a tapping is taken off; this, with a conductor from one of the outer terminals, goes to the synchronizing switches, SS. When any two machines are to be synchronized, the pressures are read on the respective voltmeters, PNM, and the half secondaries being coupled in series with each other and a lamp, L, or (and) voltmeter, SVM, taking 100 volts, co-phasal running is indicated by the lamp burning steadily, and the voltmeter indicating 100 volts. A second lamp, in parallel with the first, is usually provided in a good position for the driver, who regulates the engine speed by it, ESL.

In another form a synchronizing transformer, ST, is provided whose connections are indicated in fig. 165. One of its primaries is put across the bars by closing a synchronizing switch, SS; the other is placed across the alternator terminals by jack-cord plugs, or multiple-way switch A_1, A_2, A_3. The secondary is common to both primaries, and gives 100 volts. When the currents in each primary are co-phasal, the lamps, LL, being in parallel with each other, light up: the bus bar pressure is indicated by BBVM, and the synchronizing bar pressure by SVM. Paralleling is done through the switch PS, and fuse, PF, in the first place, as referred to above. A third and simple arrangement is shown in fig. 166, where any two machines are connected to the two sets of bars, SBA_1 and SBB_2 respectively, and two separate transformers in series, ST_1 and ST_2; the secondaries in series are joined to lamps L and L, also in series. Each transformer has a 100-volt voltmeter, in parallel with its secondary.

The usual practice with alternating generators is to adjust the speed for correct frequency on a master engine and maintain this speed as other sets are run up. The exciting current is then adjusted to bring the pressure up to the requisite amount. Where a number of machines are running in parallel attention is paid to the exciting

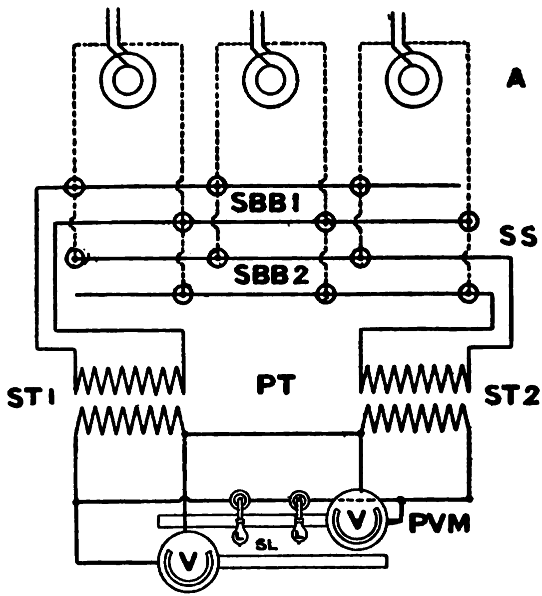


Fig. 166.

current of each, so that with a given bus bar pressure they may run together with the least synchronizing current flowing between them. One engine is run on its governors and the others are kept on the throttle valve. Steam adjustment on the throttle determines the load taken by each. Hand regulation on the low pressure cut off of compound engines enables the two cylinders to be

balanced for a steady and equable turning moment, one of the first conditions for good parallel running.

In alternating stations the machines are either excited from a special low-tension system comprising direct current dynamos run in parallel on a pair of bus bars (to which a set of secondary cells are sometimes added) or each alternator has its own exciter driven off a jack-shaft or the main shaft of the set. The advantage of the former method is the higher efficiency of a few large dynamos compared with a number of smaller ones. On the other hand, where each alternator has its own exciter there is less risk of the plant being shut down by a failure in the excitation. Many failures have occurred through trouble on the exciting system, and too great care cannot be taken with this portion of the station plant. Between the exciter bars and the alternator fields regulating resistances are inserted to adjust the magnetizing current and thereby vary the pressure of each generator. The shunt coils of the exciters are regulated by a separate resistance which enables the whole of the machines in parallel to be altered. With separate exciters a long range of adjustment is possible, the larger steps being made by altering the field current of the exciter and the smaller by a series resistance in the alternator field circuit. Care must be taken that the whole of the regulation takes place on the stable portion of the exciter characteristic, and to ensure this it is sometimes necessary that a fixed resistance should be inserted between the exciter and the alternator fixed circuit.

A mode of determining the correctness of this adjustment is to plot a characteristic for the exciting machine, on the same chart curves are drawn representing the resistance of the main field of the alternator and cables

connecting to switchboard, ordinates are then drawn for no load and full load exciting currents, fig. 167. It is then evident that to regulate by the shunt alone one must work on characteristics which fall through the point A for no load, and through the point B for full load. Judging from the curves 6 and 7, these points would fall on, or very near to, the unstable parts of the required characteristics and the shunt resistance i.e. Res. in shunt rheostat

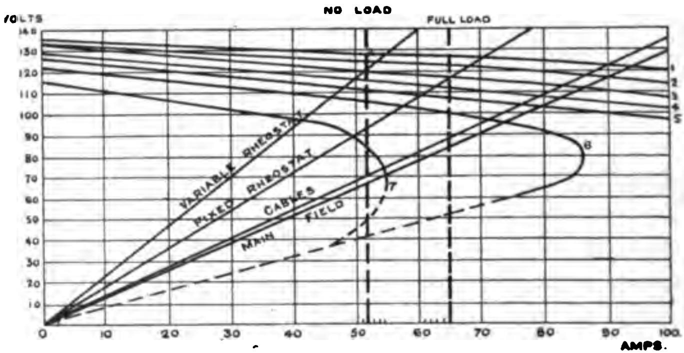


Fig. 167.—Example of determination of regulating resistance of single-phase alternator.

would be about 11 ohms and 9·6 ohms respectively giving a variation of only 1·4 ohms in shunt resistance from no load to full load.

To avoid this, it is better to work with a fixed and variable resistance in series with main field, obtaining a little extra regulation by means of the shunt to allow for abnormal overload, or for paralleling if bus bar volts are very low, as might be the case if any unexpected overload came on the rest of the plant. To get this select Charac. No. 3 as the working one, draw curve through origin and point C where No. 3 crosses ordinate for full load current. This gives amount of fixed resistance required in series

with main field. Also by cutting out shunt Res. and getting on to Charac. No. 1 an exciting current of 71 amps. can be obtained which should be ample for over load and the fixed Res. ought to be made heavy enough to carry this current. To get variable Res. draw curve through origin and point D where Charac. No. 3 crosses no load exciting current. It would be in the power of the switchboard attendant to cut out shunt Res. and get on to Charac. No. 1, thus obtaining 55 amps. with all fixed and variable Res. in, so variable resistance must be built heavy enough to carry this current through its entire range.

To allow of paralleling on low volts arrange shunt Res. so that Charac. No. 5 is the lowest that can be worked on, thus making it possible to obtain about 48 amps. as no load exciting current instead of 52. In the present case this would make the total shunt resistance required 6·87 ohms, and it would be divided up between all the stops with which the shunt switch was fitted—twelve in this case—giving a resistance of only ·624 ohms from stud to stud and consequent fine regulation. It is necessary to allow a considerable difference between full load and over load exciting currents on account of increased armature reactions, but this can always be obtained by shorting a portion of the fixed resistance. Only a small difference is necessary at the other end as a very small decrease in exciting currents drops the alternator volts considerably at no load.

CHAPTER X

TRANSMISSION AND DISTRIBUTION

WHEN the first central stations were erected in this country regulations were drafted by the Board of Trade to protect the public in the matter of safety and to ensure a satisfactory supply, but these were rather of the nature of an experiment than otherwise. This was natural, as experience in a new and highly technical business was necessary to show what it was desirable should be regulated, and how the objects in view could best be effected by imposing conditions upon undertakers. For many years stations were run in the manner best pleasing the owners and managers, and the so-called regulations effected very little. The more prudent and far-seeing engineers recognized that the time would come when the Board of Trade would cease to regard with indifference noncompliance with their requirements, and they set to work to put their house in order against the day of visitation by a Government inspector, when an inquiry into the method of running was to be expected. The Home Office has now an electrical inspecting staff, and the tendency of recent years has been for the Board of Trade to exercise a fair and impartial but thorough supervision.

One of the first provisions of the regulations was that in case of accident to any main, or when it became necessary to execute any repairs, not more than a certain number of consumers (usually eighty) should be affected,

and that the power delivered through any high-pressure main should not exceed another fixed quantity (which generally was 200 kilowatts). This proviso was in some cases overlooked, and an elaborate system of high-tension mains was laid down to distribute the current from alternating stations, which involved the shutting down of a main at the station while a new consumer was being connected or repairs made at any part of its length. In the days when house transformers were in use, there was a tendency to neglect mechanical strength in the case of mains and services, and the use of a pair of 3/20 vulcanized rubber leads tee'd by vulcanized joints to the street mains was not unknown. Faults were common on these small conductors, and the reputation of electric lighting suffered.

So long as the demand was small and consumers were few and far between, a pair of mains were laid throughout a district; as the business progressed, branches were taken off one after the other until the original cables had joints every few yards of their length. An elaborate "tree" of mains, branches, sub-branches, and services was gradually built up, its ramifications being known only to those who had put in the original conductors, and often their successors were not thoroughly aware of the position of joints, &c., consequently it became an onerous task to maintain everything in good condition.

The low-tension system did not lend itself to such practices to the same extent, but, on the other hand, abuses equally objectionable to the public—and perhaps more immediately felt by them—were permitted. Most important of all was the deficient pressure, which became a by-word amongst supply engineers; in some cases the position of feeding points could be located without difficulty by any one who took the trouble to note the relative brilliancy of lamps along a street, the pressure falling off

as the distance increased from one feeding point, until the centre of the load was reached, when the gradient changed to a rising one and the candle-power increased towards the next junction with a feeder.

So much was this felt in densely-loaded districts like those in the West-end of London, that clubs and mansions took advantage of the existence of competing companies to obtain a service line from each, and by means of a change-over switch took supply from whichever source happened at the time to maintain the higher pressure.

Regulations.—The principal provisions regarding the mains and distribution networks of concerns supplying electrical energy to the public are contained in the Board of Trade provisional orders and regulations. The definitions by which the principal parts of the distribution system are described are as follows:—A *main* is any electric line laid down in any street or other place through which electrical energy is to be supplied. A *distributor* is a main which is used to give origin to services. In provisional orders the districts in which mains may be laid are set forth, as the "area of supply," throughout which mains may be laid as required, and the "compulsory area," or district in which distributors must be laid within a certain time (usually two years from granting of the order). The system on which mains are laid must be approved, and the approval is embodied in a description of the system endorsed by an official of the Board of Trade. It is distinctly provided that no connection with earth must be permitted to exist except such connection be approved by the same authority and it be carried out in a manner detailed by them,[1] while the sanction of the

[1] The form in which such consent is given will be found in an Appendix.

Postmaster-General is also necessary, as the earth currents may affect telegraphic communication.

Before commencing to supply, the standard pressure on the distributing mains must be fixed by the undertakers. The limiting condition which principally affects the design of the distributing system is that the variation of pressure at any consumer's terminals may not exceed 4 per cent. from the constant pressure "declared" by the undertakers as that at which the supply would be given.

Data.—However great may be the desire to accurately set out beforehand the different factors incidental to the distribution, it is almost impossible to obtain reasonably correct data upon which to design the cable network. In the first place, there is no ready means by which the number or position of probable consumers can be obtained. It very often happens that thoroughfares in which a large demand is looked for when the plant is first put down turn out eventually to belie their character and prove comparatively unremunerative. On the other hand, smaller and less wealthy streets may yield a rapidly increasing *clientèle* for whom little or no provision has been made at the outset, it being thought that some time would elapse before any appreciable call for supply would be made by residents therein. In this way the heavier mains may remain only lightly loaded and the smaller branches be overtaxed before anything can be done to relieve the congested areas. Eventually the growth of the business removes such troubles, but there are many stations which have felt the pressure of circumstances in this way.

It is sometimes stated that the consideration of the theoretical size of conductors is of little importance, as the basis of calculations can only be the very indefinite data obtainable before supply is commenced. This is

rather a superficial view, as the principles require to be thoroughly mastered in any case to enable the system to be laid out with economy and at the same time ensure a good service. The experience of the past when 7/16 S.W.G. distributors were laid shows that mistakes can best be avoided by a realization of the governing principles, and these are of no little assistance in making extensions or additions to the original system later on.

Even at this late date it is not unknown for an engineer to specify mains on the tables of ultimate permissible heating, ignoring or overlooking the more important feature of drop in volts along the line. The difference between feeders and distributors is also sometimes forgotten, although these have to be treated on quite diverse grounds.

Attempts have been and are still being made to forecast the incidence of demand by canvassing the compulsory area and each extension district prior to deciding upon the most suitable size of mains, but this is usually fruitless. Business men decline to commit themselves beforehand to a promise to take a certain current, although when the mains have been laid past their doors they do not hesitate to fit up their premises and go in for electric lighting or motive power. The converse is also true, that many less considerate individuals, on being told that an expression of their intention to take power commits them legally to nothing, fill up the form presented, and appear on the book as "applicants," but, when pressed a short time afterwards as to the date on which they wish supply to be commenced, postpone a reply *sine die.* Canvassing, therefore, does not assist the distribution engineer in this respect to any great extent.

The second matter that has to be kept in mind is the necessity for providing for future extensions, the extent

and nature of which cannot be gauged. From the compulsory area branches will be taken off to side streets and into outlying districts (some of these being fed from the existing mains and others requiring new mains laid in the original conduits). There is also the certainty of growth and expansion in the compulsory area itself, and if, as is most likely, the area scheduled for supply within two years comprises the richest part of the district, this may become a very serious matter. The mistake which is most common is to under-estimate the size of conductors and lay mains which soon prove inadequate. As the cost of opening and reinstating the ground and the ducts or troughing only increases slowly with a large increment in the section of copper, it pays to err on the side of laying the larger size of main if there be any doubt.

So far we have had in view the problem as it presents itself to the engineer on starting a new supply, but the same conditions have to be met in a modified form after extensions have been put down. The extension or extensions require perhaps even more matured consideration, for distances are bound to be greater, and a number of problems connected with lamp density and pressure regulation on lengthy distributors arise. It may then be found advisable to have some regard to a change of system, and all the points that crop up have to be given due weight, while their relative importance is maintained. Nor must it be forgotten that, after all, distribution is the alpha and omega of electricity supply, for to it is due the creation of "systems," the divergence between practice in one place and that in another, and the host of technical questions that go to make up the business itself, although, as has been shown elsewhere, financial results are only slightly affected, provided the system is suitable for the nature of the load in the district.

Sub-stations.—When the limit of economical distribution direct from a central station is reached, it becomes necessary to form subsidiary centres from which to distribute. These sub- or transforming stations take the place of additional generating works, and what was a simple system of distribution becomes one of separate transmission and distribution. Sub-stations have been employed with low-tension direct supply to contain batteries and balances, but their more extended use to-day is as centres of transformation. As the mains from the generating works to the sub-stations are wholly under the control of the undertakers, there is no limit to the pressure that may be employed, and for economical reasons the pressure of transmission is being pushed to higher and higher voltages. Roughly speaking, it does not pay to distribute to a greater distance than two miles from the generating centre, and when a high-tension system has been put down, the facilities afforded for transformation make it desirable to reduce the distance covered from any sub-station, this being especially the case in districts of dense demand and where the output is rapidly increasing.

The present limit to the pressure of transmission is about 12,000 volts, beyond this it is doubtful if the advantages compensate for the disadvantages entailed by extremely high insulation, such as is imperative in a humid climate and interference due to resonance and other capacity effects makes itself felt on the mains. In this country also the whole of the cables have to be placed out of reach underground, rendering it out of the question to attain to the economies which overhead conductors with their supports only at intervals have placed in the hands of foreign engineers.

The frequency of alternating currents have been reduced from the 130 and 100 periods formerly the rule for lighting supply to 50 periods on mixed systems of lighting and power, and now 40 is the generally accepted figure for lighting, power and traction with the still lower 25 periods where power transmission alone has to be arranged. The Engineering Standards Committee have selected 50 and 25 periods respectively as the most suitable frequencies for a mixed and a purely power supply respectively, and these figures are accepted as correct by the majority of engineers.

General Principles for the most part are not affected by the choice of system, whether continuous or alternating, direct or converted, *as such*, but can be determined by taking into account loading, pressure at the terminals, length, and similar factors that have necessarily to be known for every case of conduction.

Copper being the metal universally used as a conductor for large currents, we may confine our remarks to it. The most important problem in distribution on any given system is to determine the size of the conductors, and, having found a suitable size, the form they will take has to be decided.

Mechanical Strength.—A conductor must have sufficient mechanical strength to allow of its being laid without risk of breaking. In the case of insulated cables in which the conductor consists of stranded wires, if these are of too small a gauge the insulation may be pierced by the broken ends at the place of rupture. During manufacture, and laying, the cable as a whole is repeatedly wound and unwound, and may have to be "flaked" on the street if obstacles are met with when being put underground. If the conductor itself is deficient in strength, some of the

strain may come on the insulation, which may then be cracked or injured, while it is certain to be distended and its electrical qualities deteriorated. For these reasons the Board of Trade has fixed the minimum size of any conductor laid in any street at the area of a circle one-tenth of an inch diameter, and if the conductor is formed of a strand of wires, each separate wire must be at least No. 20 S.W.G.[1]

Pressure Drop.—The resistance of a copper conductor depends upon the purity of the metal, its mechanical state and its temperature. The specific resistance (per cubic centimetre) of conductor copper may be taken as 1·6 microhms, giving a resistance per foot-grain of 0·2 microhms, and per mil-foot of nearly 10 microhms. The resistance of a bar of one square inch sectional area and 1,000 yards long is therefore approximately 0·022 ohms.[2]

For practical purposes it is most convenient to state resistance in terms of the voltage drop per 100 yards at a given current density. As the distance is usually a fixed quantity, and the permissible drop is known, the greatest possible current for a given size of conductor in actual use has to be found. Taking cables, &c., as laid and connected up, an approximate rule is that "with a current density of 1,000 ampères per square inch of sectional area the drop is five volts per 100 yards run (i.e. per 200 yards of lead and return conductor taken singly).

[1] For a description of wire-drawing and a discussion of tensile strength, &c., see *A Treatise upon Wire*, by J. Bucknall Smith.

[2] For information upon the effects of impurities, mechanical state and temperature on the resistance of copper, see Matthiessen and Hockin, *Phil. Trans. R.S.*, 1857-1864, Tomlinson, Kennelly and Fessenden, *Proc. Inter. Elect. Cong., Chicago*, 1893, Fitzpatrick, *B.A. Reports*, 1890.

This may be written[1]:—

Let A = Current in ampères to be conducted.
„ D = Distance in yards out and home.
„ V = Permissible volts-drop in circuit.

then $\frac{A \times D}{V \times 4}$ = Sectional area in ·0000 square inch.

Heating.—The pressure-drop due to conductor resistance represents a degradation of power which appears as heat, the magnitude of the loss being fixed by Joule's law. This heat is removed from the conductor by radiation, by conduction, and by convection, and the temperature of the conductor rises until the rates of heat generation and dissipation are balanced. This final or stable temperature so largely depends upon the thermal environment of the conductor that it is an extremely difficult matter to predetermine it for any practical case, and such knowledge as we possess on the subject has been obtained empirically. The maximum permissible temperature of any part of any conductor has been prescribed by the Board of Trade as 30° F. above external temperature, and this proviso fixes the maximum working current for any main or cable. The researches upon heating are numerous, but most of them refer to cased wire or bare conductors; in only a few cases have experiments been made upon cables laid in permanent works.[2]

Dielectric hysteresis and the losses which occur on alternating systems by reason of cyclic charging and discharging of the insulating medium on cables have received exhaustive treatment since the first edition of

[1] T. O. Callender. *Elect. Review*, p. 165, February 18th, 1887.

[2] The following papers should be consulted:—Forbes, *Journ. Soc. Tel. Eng.* 1884; Preece, *B.A. Reports*, 1889; Kennelly, *Proc. Edison Convention*, 1889; *Proc. Edison Convention*, 1893.

this work. Mordey has shown that with cables working at 7·500 volts and 50 periods 870 watts may be lost per mile on a ·1 sq. in. or 19/14 S.W.G. cable owing to the soaking in on the dielectric.[1] And another example was given later that a cable for three-phase working at 10·000 volts might waste 7·400 units per annum. It is generally considered that the loss on modern low capacity cables does not exceed one-tenth of the figures found in testing the samples for which most of the data is available. Difference of opinion still exists as to the precise character of the losses in question and also as to their magnitude, but there seems to be little doubt that the dielectric does absorb a certain though relatively small quantity of energy on each reversal of the charging current.

Effect of Adjacent Conductors.—Cables carrying continuous currents exercise little appreciable action upon one another. Single cables are therefore freely used. With alternating currents the inductive action becomes of importance, and single lead-sheathed cables are objectionable owing to the sheathing acting as a closed secondary circuit to the line conductor as a primary. Twin or double conductors separately insulated and enclosed in a common armouring or sheathing give better results, particularly if the conductors are given a spiral lay round a common centre, but complete immunity is only gained with concentric conductors in which one entirely surrounds the other.

With alternating currents not only does the varying magnetic field round the conductor exercise an effect on neighbouring conductors, but one element of the current acts on other elements, giving rise to a mutually-repulsive

[1] *Inst. Elect. Eng.*, January, 1901.

action from the centre of the conductor to which the term "skin resistance" has been applied. Maycock suggests the more appropriate term "conductor-impedance."[1] Mordey[2] has calculated a table—which is given in most pocket-books—showing the magnitude of this effect with various-sized conductors and different frequencies. As, however, 300,000 watts is the maximum power that is transmitted by most high-pressure cables, the largest alternating current that has to be considered in general is 150 ampères, and the conductor-impedance effect on a conductor of 0·20 sq. in. section is not sufficiently serious to require elaborate treatment. With larger cables, such as 0·4 sq. in. distributors, the increase in apparent resistance may amount to as much as 8 per cent., with a frequency of 100 periods. The question of alternating currents in a low-tension distributing network has been discussed by Parry[1] and Field.[2]

Losses in Distribution vary between large limits depending upon the size of an undertaking, the system adopted and the kind of load. An idea of the losses which actually occur are given below, but it must be remembered that against "loss" is set any quantity not registered by consumer's meters. The units generated are usually metered on the switch-board, and the difference between the sum of this quantity and the units used for motor driving and lighting in the works is "not accounted for," and regarded as copper and leakage losses on the mains.

[1] *Alternating Current Circuit*, p. 78.

[2] *Journ. Inst. Elect. Eng.*, May 23rd, 1889.

[3] *Proc. Phy. Soc. Glasgow Univ.* Reprinted *Elect. Eng.* March 9th, 1894.

[4] *Journ. Inst. Elect. Engrs.*, April, 1904, vol. xxxiii., p. 936; and *Journ. Inst. Elect. Engrs.*, vol. xxxi., p. 138, 1901-02.

A careful analysis of the losses on an alternating system was made a year or two ago,[1] which showed that the various items over which the accounted for units were taken bore the following proportion:—

Kind of Loss.	Annual Units Wasted.	Total.	P.c. of Units Generated.
Losses in switch-boards and connections...	10,000	10,000	·5
H.T. Feeders, leakage and dielectric hysteresis	16,400		
H.T. Feeders, C^2R or heating of copper ...	47,200		
L.T. Distributors, leakage and dielectric hysteresis	2,000	169,000	8·7
L.T. Distributors, C^2R or heating of copper	66,200		
Arc Circuits, C^2R or heating loss	37,200		
Transformers, core loss	109,500	173,200	8·9
" copper loss	63,700		
Meters, C^2R or heating loss	1,750	532,50	2·7
" shunt current loss	51,500		
Total wastage accounted for		405,450	20·8
Units used in station	—	111,000	5 9
Units sold to consumers	1,502,000	—	—
Less difference in meter readings	40,550	1,431,550	73·5
Units generated in station		1,948,000	100·0

Maps and Plans are required to enable the various works comprising the system of distribution to be shown. With the memorial deposited by applicants for a provisional order or license at the Board of Trade must be included a map of the district termed the *Deposited Map.*[2]

Before opening or breaking up any street a plan must be sent to the persons having the control or management thereof.[3] This plan must be

[1] Constable and Fawsett. *Inst. Elect. Eng.*, March, 1903.

[2] Rule 5 of those made by Board of Trade with respect to applications for Licenses and Provisional Orders.

[3] Sec. IX. Gas Act, 1847 (Incorporated Elect. Light. Act, 1882, Sec. 12).

to a horizontal scale of at least one inch to eighty-eight feet (five feet to the mile), and where possible a section drawn to the same horizontal scale as the plan to a vertical scale of at least one inch to eleven feet, with such sections and details as may be necessary.[1] The local authority and Postmaster-General are entitled to copies of such plan one month before the works shown thereon are proceeded with. This may be called a Notice Plan.

A map of the area of supply, showing the line and depth below the surface of all existing mains, service lines, and other underground works and street boxes, has to be kept by undertakers, who are required at least once a year to duly correct the same so as to show all existing lines.[2] This is the Statutory Map of the distribution works, and is usually drawn to the scale of five feet or ten feet to the mile.

On completion of each section of new main a plan to the scale of ten feet per mile, showing depths and distances horizontally, must be served upon the Postmaster-General.

For the purpose of obtaining municipal loans a plan of the proposed works has to be submitted to the authority authorizing such loans (the London County Council in the Metropolis, the Local Government Board for the provinces). This plan should be in duplicate, so that a correct copy may be retained with a copy of the loan papers for reference.

When a plan has been approved by the local authority or Board of Directors for the execution of distribution works this should be marked Departmental Original; a copy of this being provided for the distributing engineer is marked Office Copy.

The foregoing are the principal maps and plans required for general use. To enable the distribution data to be readily obtained it is advisable to prepare certain other maps and plans as described below.

A map of the district to the scale of 5 ft. to the mile is usually large enough to enable the mains and position of consumers to be indicated. If, however, the ordnance maps are not sufficiently clear, a larger map of details should be prepared to double this scale, and this will be found convenient to take copies for the Postal Telegraph Department. As each consumer's application is received his premises should be pencil-hatched on the map, and when connection has been made the pencilling can be rubbed out and the premises washed in with colour. To save duplication this should be done on the "statutory map," which also

[1] Secs. 2 and 12 of Provisional Order.

[2] Sec. 6 E. L. Act and Prov. Order, ss. 25-27.

shows mains, &c., and is kept as a full general record of street works, and serves as an index to details.

A smaller map to a scale of 1 ft. to the mile forms a convenient glance map, enabling the relative distribution of custom to be ascertained. Lithographed sheets of the supply area to the scale of 6 in. to the mile are useful for showing such particulars as streets in which mains have been and are being laid; positions of feeding-points or sub-stations; location of street arc lamps, &c.

The arrangement of boxes and connections between mains is most conveniently shown in a foolscap book, and can be sketched in boldly to show what is required in a manner that cannot be attempted on a plan, however large. Such books are convenient because all data can be collected and written in against the sketches, thus avoiding loose reference sheets. The length of each street or road should be carefully measured on the large scale map and recorded in an appropriate book for future use. From the particulars so furnished, and with the assistance of the maps, density tables, street load curves, and so on, are readily prepared.

Feeders.—When dealing with the position of the generating station in Chapter III. it was shown that its location depends upon such factors as cost of land for site, water supply, facilities for obtaining coal, avoidance of nuisance, character of foundations, and subject to these one would prefer to place it symmetrically with respect to the thoroughfares in which consumers are situated. In other words, the shorter all the mains are the better, and to reduce all losses to a minimum the station should be placed in the centre of the area supplied, assuming the consumption reasonably uniform throughout. Theoretically it is an easy matter to determine the best position by postulating a given average consumption per yard of frontage and finding the electrical centre of gravity of the system. Unfortunately, stations cannot be located as a rule in this way, because the commercial considerations are of first importance. Again, it is almost impossible to forecast the directions in which large and important

extensions may be required. One is therefore compelled to pay most regard to the obvious conditions which render a site eligible or ineligible, and then design the feeder or transmission system to suit the location of the station.

Nearly everything that has been written on the subject is based upon the fact that if a given current has to be transmitted to a certain point, and the generating centre be removed to double its original distance from that point, then for a given drop of pressure the weight of the conductor will be quadrupled, because its length has been doubled, and its section must also be doubled, for the voltage drop to remain constant. Thus:

$$\text{Conductor weight} \propto \frac{\text{current} \times \text{length.}^2}{\text{drop}}$$

Therefore the only things affected by altering the location of the generating centre are (*a*) the weight (and therefore the cost) of the feeders, and (*b*) the load losses in the feeders. Either *a* or *b* may be kept at a constant value by allowing the other to vary as indicated in the above proportionality. The feeders, however, are not directly revenue-earning, and any unnecessary increase of capital expenditure in this direction tells against the capital cost, the up-keep cost, and the load loss cost. Also it may be impossible to efficiently utilize the system of supply (say, direct supply without conversion) which is otherwise most suitable for the district should the generating centre be removed to a distance from the consumption area, and consequently a less desirable method may have to be used to enable supply to be given at all.

All locations are equally suitable, from a distribution stand-point, that are the same distance from the best

position of the station, supposing the consumption uniform throughout a symmetrical district. Although the problem is readily amenable to mathematical treatment, little is gained, as the engineer has to meet the conditions found in practice and cannot directly utilize theoretical deductions.

When a system is first projected it is usually possible to fix upon likely points to which the feeders may be brought, and, as the output increases other feeders are called into use, and, if necessary, the first selected points are discarded and others substituted to meet the requirements of each case. Of course, with a closed-in system of mains, changes of this sort are more or less out of the question, but experience has proved the advisability of doing one of two things: either the mains are buried in the ground directly, and boxes are inserted at comparatively short intervals, or else a draw-in system is laid down, and the original conductors can be removed and relaid, or any alterations in position and size made when and where they seem advantageous. The location of feeding-points at the intersection of principal routes of distributing mains is indicated, together with position of central station, CS, distributors and consumers in a case of imaginary supply in fig. 168.

Distributors are laid so as to form a conducting system round the feeding-point from which they derive their supply of energy. Adjacent conducting systems are sometimes interconnected in such a way that a plan of the network has the appearance of a spider's web. This is held by some engineers to be the proper thing, as it enables one feeding-point to assist those round it, and certainly the practice does tend towards improved distribution. On the other hand, there are partisans of isolating each distri-


NORTH GATE
CATHEDRAL
HIGH ROAD
LOWER ROAD
FP1
PP
PP
CLIFTON BRIDGE
RIVER
FP2
FP3b
PP
PP
CS
FP3a
FP4
DIVIDING POINT
SOUTHGATE
VICTORIA BRIDGE
0
100
200 YDS

Fig. 168.

buting system, and they point out that a short circuit, occurring anywhere on a network, may be a serious matter, as a large area will be affected, and the task of locating a fault is a formidable one. With independent networks a higher insulation can be obtained than if the mains serving a large district be connected together. To get over this difficulty it has been suggested that where the system is alternating a number of small local networks should be used, each being complete in itself, and not metallically joined up with any other part; where it meets the network of the neighbouring district it would be connected through to neighbouring networks by one-to-one transformers sunk in the ground.

Distributors fed at both ends will have the point of lowest pressure somewhere about the centre, approaching more nearly to it as the load becomes more uniform. The ends are usually kept at constant pressures, which are the same in the case of adjacent feeding-points, or slightly varying if the points be some distance apart and the load on one materially exceeds that on the other. With perfect regulation the load would not, however, affect the pressure. The determination of the point of lowest pressure then settles at once how much current enters the distributor from each feeding-point. The lowest pressure occurs at that place which may be called the meeting place of two drainage areas, as the feeding-points can be regarded as electrical watersheds on the system of mains. If the distributor is to be cut so as to separate one section from the other and reduce the risk that would be incurred by running by an interconnected network of low-tension mains, then this cutting should take place at the point or points of lowest pressure, as the normal loading on the system and the pressure-drop would not be affected.

Street Load Curves are plotted by setting out a base line on the same scale as the map, or as otherwise may be convenient, and pricking or dotting off on this base the points where the various services tap the distributing mains. The distances on the diagram are proportional to the actual distances as measured along the route of the mains. At the points found perpendiculars are erected proportional to the respective consumers' demands, the scale for ampères being any convenient one which will give reasonable dimensions to the ordinates. The tops of the ordinates are then connected together, and the result is the street load curve.

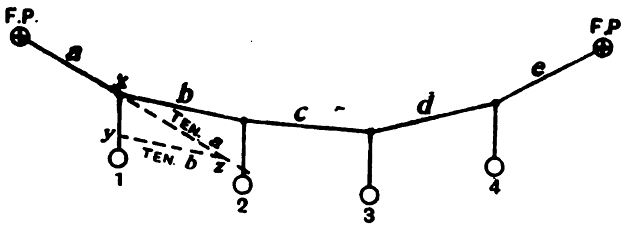


Fig. 169.

The distribution of pressure and load along a cable fed at both ends is similar to the distribution of stress in a flexible rope suspended by being held at each end and loaded with masses at intervals along its length. In the latter case the principle of the funicular polygon can be applied, and very simple graphical construction will determine the polygon if the magnitude and line of action of the masses be given, or if the form of the rope and one of the masses be given the rest can be found.[1] Thus, if masses 1, 2, 3, and 4 be suspended by vertical strings

[1] *Applied Mechanics*, Cotterill, p. 14. *The Science of Mechanics* (Mach McCormack's translation), p. 33.

from a system of ramifying strings like that shown in fig. 169, the magnitude of the tensions in the vertical strings will be numerically equal to the masses they severally support. To find the tension in *a* and *b*, produce *a* as shown; draw a line vertically through the point of support of mass 1 to indicate the direction of its gravitational action, then having set off on this last line a length to represent the load ($x\,y$) and proportional to the mass 1, draw a line parallel to *b* through the point *y*, cutting *a* produced at *z*. Then to the scale of $x\,y$, $x\,z$ is the tension

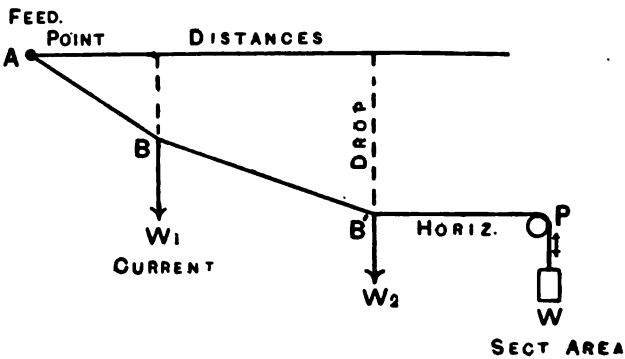


Fig. 170.

in *a* and $y\,z$ the tension in *b*. In like manner the tensions in *c*, *d* and *e* can be found. The length of a normal to $x\,y$ through *y* will give the horizontal tension in the string.

An analogous process employed to find the factors relating to electrical distribution is indicated in fig. 170. One end of a cord is fixed at A, while the other passes over a pulley and carries a weight, W. The pulley, P, is movable in a vertical direction. Attached to various points, B B′, in the cord are weights, W_1 W_2. The position

of P is adjusted until the last section, B′ P, of the cord is horizontal. The electrical factors are then indicated to scale as marked (drop, &c.). Of the simpler and more generally useful office methods, those which have been most largely used to obtain distribution data are the production of models to scale in which actual experiment shows the relationship that exists between the values in the model, and therefore what may be proportionately expected with the full-sized cables; secondly, mechanical analogues of the cable system, in which levers, strings, and weights correspond to conductors and power; and, thirdly, arithmetical calculations of an elementary kind by which the different values required are obtained from a knowledge of the physical characteristics of the materials to be used. The first and second methods are employed very freely by continental engineers, but do not seem to have received an extended application in this country. The operations of arithmetic, assisted by carefully calculated tables, are more frequently to be met with.

Mechanical Apparatus is included in the Helberger system, to be used in determining the sizes, pressure-drop, and other factors in a

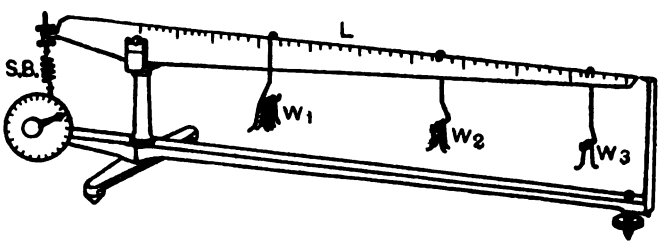


Fig. 171.

system of distribution. In fig. 171 a calculating balance is shown which has for its object the working out of the requisite sectional area of mains. It consists of a two-armed lever, of which the long arm is

graduated, and the short arm is fitted with a spring balance and pointer. In use, weights, proportional to the number of lamps or current, are hung on the graduated arm at distances from the fulcrum corresponding to the actual distances of the lamps from the source of supply, and the spring is then screwed up until the lever floats opposite the fixed pointer. The index on the scale then shows the sectional area suitable, allowing for the pressure-drop admissible.

The larger apparatus, fig. 172, enables the sectional area, pressure-drop, and distribution of current in a net-work of mains fed at various

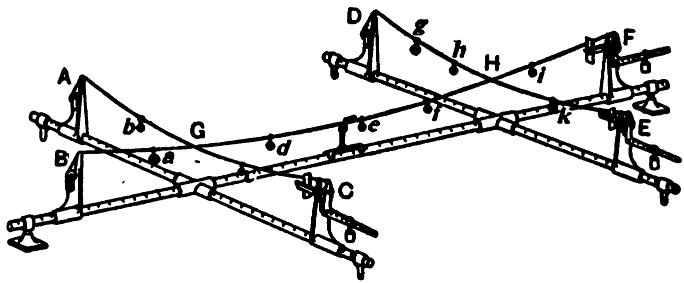


Fig. 172.

points to be ascertained. The apparatus is built up of several cylindrical graduated rails, which can be connected together crosswise. On each of these rails two movable supports are mounted, which carry the other parts necessary to adjust the threads and read off the results, while a number of weights and an arrangement to determine the sag of the thread are also included. The movable supports are arranged on the rails so that their relative distances apart are proportional to the length of the mains between the feeding-points. They are then connected together by threads on which weights, proportional to the number of lamps or current supplied, are hung at distances corresponding to the relative distances apart of the service cables. The sliding weight on the lever carried by the support is now adjusted until the sag of the thread corresponding to the pressure-drop nowhere exceeds a given amount. The position of the sliding weight then affords a measure of the sectional area of the distributing main, while the declination angle of the thread from the horizontal indicates the power taken off along each main. This is read off on a small scale mounted on the lever support. In the figure, A C, B F, D E represent distributing mains; A, B, C, D, E, F, feeding-points, and *a*, *b*, *c*, *d*, *e*, *f*,

&c., are points where current is taken off, the power being represented by the weights. G and H are tapping-points between distributors normal to one another.

A calculator has been designed by Mr. H. Hastings for use in settling the size of cables from data giving the power to be transmitted, the distance, pressure, power-factor, allowable percentage pressure-drop, and system of distribution. The apparatus consists of a number of discs with logarithmic scale upon the edge of each. The discs are released in turn, while a key is pressed and the number corresponding to each factor is brought to the zero point; by means of a handle the summation of the various factors takes place, giving the required particulars on a seventh or final disc. This apparatus is made by Mr. R. W. Paul.

Determining Drop by Calculation.—The least complicated element of a distributing system is a main fed at each end. To find the point of lowest pressure by calculation is a simple matter, provided the position of consumers is given and the current taken by each.

The pressure-drop along a conductor of resistance R when C ampères flow along it is

$$E = C\,R$$

which may be written

$$E = C\,L\,r$$

where L is the length in yards, and r is the resistance per yard.

In the same way the drop may be found for the case of a distributing main, where current is taken off at intervals, by considering individually the various currents and the resistance each circuit includes. Suppose that currents C_1, C_2, C_3, C_4, C_5, &c., are taken off respectively at distances l_1, l_2, l_3, l_4, and l_5, the drops due to each are:—

$$e_1 = C_1\,l_1\,r \qquad e_4 = C_4\,l_4\,r$$
$$e_2 = C_2\,l_2\,r \qquad e_5 = C_5\,l_5\,r$$
$$e_3 = C_3\,l_3\,r \qquad \text{\&c.}$$

and by summing the individual drops the total drop is obtained up to the last point considered, thus the total drop E up to the point l_5 is given by:

$$E = \left\{(C_1\,l_1) + (C_2\,l_2) + (C_3\,l_3) + (C_4\,l_4) + (C_5\,l_5)\right\}r$$

The point of lowest pressure is the electrical centre of the main; consumers on one side are fed from the feeding-point at that end, and those on the other side are supplied from the second feeding-point. Obviously, the total drop from the first feeding-point must equate to the total drop from the other feeding-point.

For the purpose of office calculation it is important to set out the data, so that any change in demand by any consumer may be readily allowed for without having to repeat all calculation from the beginning. We shall therefore show one of the best methods of tabulation based on the foregoing simple argument. We will call the feeding-points F.P. 1 and F.P. 2 respectively, and we know that:

$$\Sigma (\text{C}_1 \text{L}_1) = \Sigma (\text{C}_2 \text{L}_2)$$

where $\text{C}_1 \text{L}_1$ represents the sum of the individual products of current and distance from F.P. 1,

and $\text{C}_2 \text{L}_2$ represents the sum of the individual product of current and distance from F.P. 2.

Let us call the product $c\,l$ a current-moment,[1] then $\text{C}_1 n l_1 n$ will be the current-moment of consumer n about F.P. 1, and $\text{C}_2 n l_2 n$ in like manner the moment about F.P. 2.

We now take the distance of each consumer from each of the two feeding-points, and the current supplied to him, and put down the products, together with his name and demand, under the following heads:—

CONSUMER'S MOMENTS.

Consumer	Demand in ampères	Distance in yards		Current-moments		Sum of current moments	
		From F.P. 1	From F.P. 2	From F.P. 1	From F.P. 2	From F.P. 1	From F.P. 2

The point of lowest pressure is indicated by the figure given in the column "Sum of moments from F.P. 1," equalling the figure in the adjacent column, "Sum of moments from F.P. 2," because in this case the drops on either side of this point are equal. But it does not necessarily follow that two equal sums of moments will appear in the tabulation.

The maximum pressure-drop along the length of the main will equal the sum of the moments from feeding-point 1 (up to and including the current sent from F.P. 1 to the consumer at the L.P. point), multiplied by the resistance per yard of the main. The point of lowest pressure

[1] Although the term "moment" as here used differs from its proper meaning in mechanics, it is convenient to have a simple name for the product $c\,l$, and there is no objection to the term if its use be clearly understood.

or of maximum drop may be regarded as the foot of the electrical gradient along the main; here the sum of the moments from F.P. 1 will equal the sum of the moments from F.P. 2. (*a*) Those consumers between the L.P. point and feeding-point 1 will take their current from F.P. 1, and those between it and F.P. 2 in like manner are supplied by F.P. 2; (*b*) the consumer situated exactly symmetrically, and on the L.P. point obtains half his current from F.P. 1 and the other half from F.P. 2; (*c*) the consumer at the L.P. point may be unsymmetrically situated with regard to the feeding-points, and his current may be divided in some other ratio than half and half, should the loading be such that the *rate* of drop of pressure on either side of his service connection be unequal.

From what has been said it is evident that the L.P. point can be found by inspection of the columns giving sums of moments (and this will be clearly shown in the example in following pages), but to ascertain the true loading on the feeding-points we have to determine the ratio referred to above in (*c*).

Determination of Load on Feeding-points.—We have to note that if the columns of "Sum of current-moments" show two values equal to one another, one for the right-hand feeding-point against a certain consumer, and another for the left-hand feeding-point against a second consumer situated on the left-hand side of the first, then no current will flow in the intermediate length of main, and the load on each feeding-point can be found by simply adding together the currents taken by the consumers lying between the lowest pressure point and the respective ends of the main.

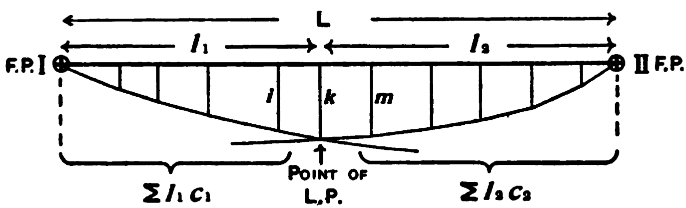


Fig. 173.

Very seldom, however, will this be the case. It will generally be found on examination of the tables that the lowest pressure point occurs at the junction of one service with the main or at the position of a service box. Then it is evident that current is flowing to this point from both feeding-points, that is, the total current there taken off

is partly supplied from one side of the main, and partly by the other. Under these circumstances we have to find out how much current comes one way and how much the other way to enable the loading on the feeding-points to be stated.

Let k = total current in ampères taken by consumer K
x = current supplied to K from I
and y = ,, ,, II
then $k = x + y$
and $y = k - x$
while

$$\Sigma (l_1 c_1) + (l_1 x) = \Sigma (l_2 c_2) + (l_2 y)$$

It may be well to explain briefly why the equation takes the form shown. The balance about the point K may be simply written after Ohm's law :—

Sum of current moments up to and including part of k from I = Sum of current moments up to and including part of k from II

because if the currents were taken to K alone we could write,

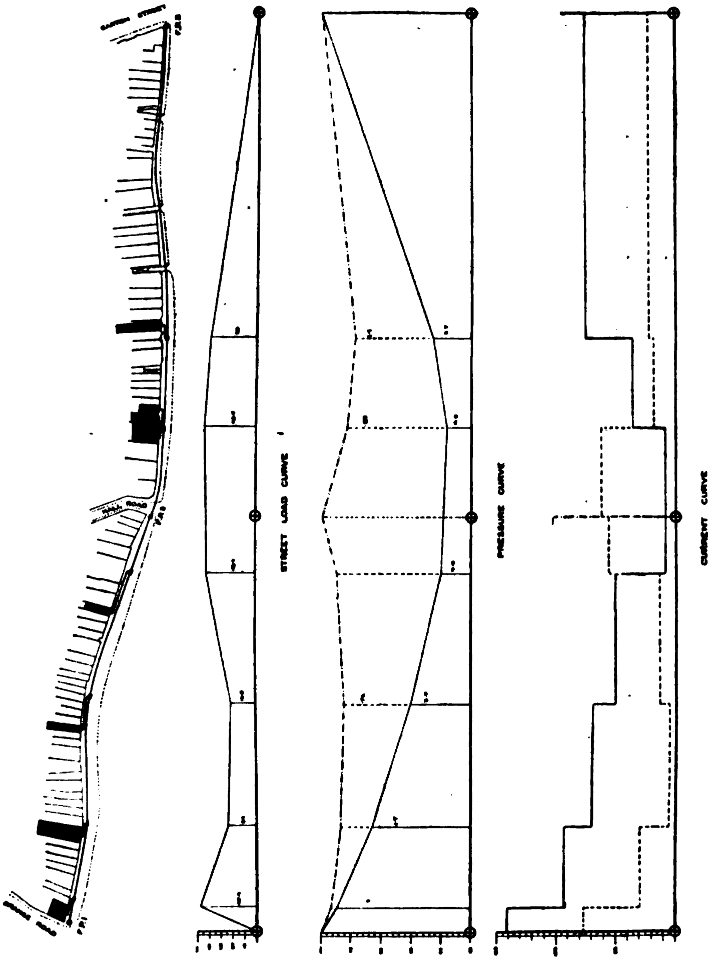
$$x \times \text{resistance of part } l_1 = y \times \text{resistance of part } l_2,$$

and the current moments are proportional to the pressure drops due to the currents taken by each consumer along the main, taken individually. The sum of the moments is therefore proportional to the drop up to the lowest pressure point, and would be equal to this if, instead of taking the distance in yards from each feeding-point, we took the actual resistance of the main up to each consumer.

The drop in volts along the distributor may be determined after the point of lowest pressure together with the current flowing thereto from each feeding-point is obtained. The current flowing along every part of the cable is now known. As usually it is chiefly required to find the maximum drop between the feeding-points, this is most easily obtained by adding the moment of the balancing current, found in the above equation flowing to the point of lowest pressure from one of the feeding-points, to the sum of the moments at the point immediately preceding it on the same side. The sum of moments thus obtained for the point of lowest pressure must be multiplied by the resistance of one yard of the cable; the drop is then given directly in volts. For intermediate points the drop may be obtained in a similar manner, using, however, for the sum of the moments, the actual values of the current flowing in each section.

An example taken from practice is given below. Figs. 174, 175, 176, and 177, show respectively a plan of the street, street load curve, pres-

sure curve and current curve. The table gives the method of working on the foregoing principles. The dotted lines in figs. 176 and 177 indicate the effect of adding an additional feeding-point at Hall Road in fig. 175.

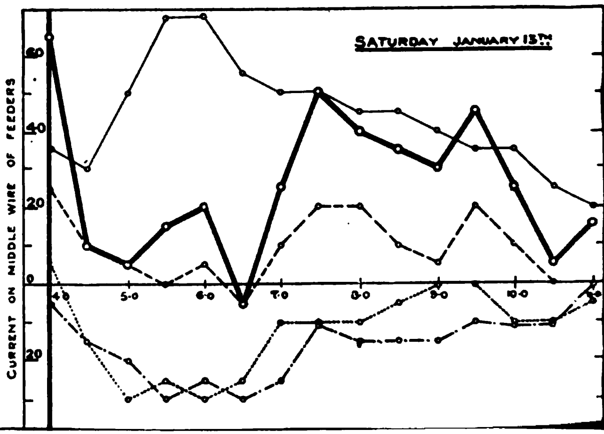


Figs. 174, 175, 176, and 177.

Name of Consumer	Demand in ampères	Distance from Barton Street (yards)	Distance from Grange Road (yards)	Moment from Barton Street	Moment from Grange Road	Sum of moments Barton Street	Sum of moments Grange Road	Volts drop R = 25×10^{5}	Load	—
Barton St.									75 ↓	
Brown .	39·9	200	365	7,980	14,560	7,980	—	3·7		
Green .	3·2	255	310						↓ 35·2	Point
Black .	24·5	255	310	11,140	13,550	19,120	27,902	4·2	8·5	of
White .	16	255	310						↑	L. P.
Hall Road.										
Jones .	42·7	345	220	14,730	9,394	33,850	14,352	4·0		
Robinson .	19·2	425	140	8,160	2,688	42,010	4,958	3·0		
Smith .	24	500	65	12,000	1,560	—	2,270	1·7		
Tait . .	47·4	550	15	26,070	710	—	710	·5	↑	
Grange Rd.									142	

Name of Consumer	Demand in ampères	Distance from Barton Street	Distance from Hall Road	Moment from Barton Street	Moment from Hall Road	Sum of moments Barton Street	Sum of moments Hall Road	Volts drop R = 25×10^{5}	Load	—
Barton St.									22	
Brown .	39·9	200	110	7,980	4,389	7,980	6,792	1·1		Point of L. P.
Green .	3·2	255	55						18 ↑	
Black .	24·5	255	55	11,140	2,403	19,120	2,403	·85		
White .	16	255	55							
Hall Rd.		From Hall Road	From Grange Road	From Hall Road	From Grange Road	From Hall Road	From Grange Road		↑ 61·7 56·3 ↓	
Jones .	42·7	35	220	1,494	9,394	1,494	14,352	·48		
Robinson .	19·2	115	140	2,208	2,688	3,702	4,958	·76	↓ 13·6 5·6 ↑	Point of L. P.
Smith .	24	190	65	4,560	1,560	8,262	2,270	·66		
Tait . .	47·4	240	15	—	710	—	710	·29		
Grange Rd.									↑ 77	

Application of Curves.—The street load curve, pressure curve, and current curve, for the practical case which has already been considered, are given in figs. 175, 176, 177. In the first of these the vertical lines represent consumers, the height of the ordinate to scale is a measure of the



SATURDAY JANUARY 13TH
CURRENT ON MIDDLE WIRE OF FEEDERS
60
40
20
0
20
4·0
5·0
6·0
7·0
8·0
9·0
10·0

current taken off at each point. The curve joining the tops of the ordinates denotes nothing in particular, but affords a convenient means of calling attention to large loads and acts as a characteristic, inasmuch as its uniformity means that consumers do not vary much in their requirements, whereas erratic changes in level can only be put down to the presence on the frontage of very different classes of consumers, of widely varying importance and of a consequent irregular loading on the mains. A curve might be obtained from this in which each ordinate was the sum of all the ordinates (measured at positions where consumers come on) between the point in question and the feeding-point. We should then derive a current curve for a main fed at one end, but with mains fed at both ends it is better to plot such curves as in fig. 177. Before the true current curve can be drawn, it is essential that the point of lowest pressure should be found, and the pressure curve along the main plotted. This is given in fig. 176. In the two bottom figures the full curves in each case correspond, and the dotted curves do likewise.

It will be seen that the base lines are the same for each curve, and are directly proportional to linear distances measured along the mains. The circles and squares indicate the positions of feeding-points, the pressure on each feeding-point being the same as on the others.

Balancing Three-wire Distributors.—The difficulties attending three-wire distribution where mistakes have been made at the beginning by non-attention in connecting consumers when the load was small, are clearly shown by the curves of actual unbalanced current, in a certain instance with which the writers have been favoured. (Figs. 178, 179, and 180.) When later consumers come on quickly the only alternatives are to combine and balance the various networks as much as possible or to change over the services. To meet such circumstances as those shown, it is necessary to plot unbalanced load curves for each street, and it may take some time before anything workable can be obtained that will illustrate the true state of things (fig. 181). The following process may be followed :—

A length of cable is taken between, say, a disconnecting box and a feeding-point. On curve paper with ampères as ordinates and length

of street as abscissæ the consumers' demands are plotted in vertical columns at distances proportional to length from feeding-point. Plotting the resultant from end remote from feeding-point gives current flowing

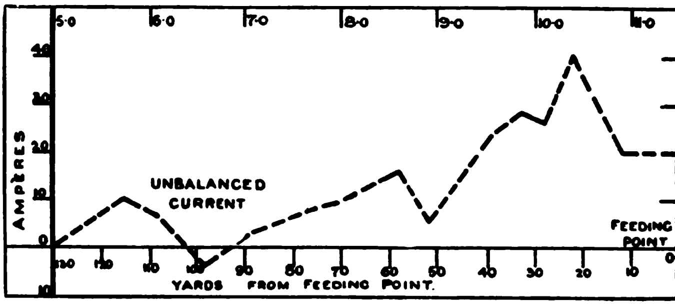


Fig. 181.

through neutral at any point. If this be done systematically (fig. 181), it may be found that certain portions of distributor are working at a current density of over 5,000 ampères per square inch, and under such circumstances it is not surprising if the distribution efficiency be as low as 85 per cent.

Networks and Boxes.—The first object of the distribution engineer should be to carry out his work so that the constancy of supply may be beyond question: there is nothing which tells more in its favour than reliability. Secondary to this, economy, both in first expenditure and maintenance, and in the minimizing of losses in the conductors should be aimed at. Both of these ends are assisted by a proper use being made of tapping mains, or conductors connecting two adjacent low-tension networks or parts of the same network which is fed at a remote point. Very often the growth of the business requires a low-tension main to be laid in a side street or on the opposite side of a street to that in which a supply is available. Instead of running feeding mains or laying down a converter for this extension, on which the demand may be

for some time small, cross-street mains may be put in so as to feed it from the existing live network. Or as time goes on it may be found that two branches of a network spread out away from the feeding-point, but approach one another like ingrowing horns. An appreciable benefit may then be derived by bridging the two extremities, as the one horn can supply power to the other should it, at any time, be overloaded. Wherever tapping mains are used they should terminate at each end in junction-boxes, where provision should be made for readily connecting or disconnecting the conductors.

It is often the case that a main thoroughfare has one network on one side and another on the other, these being fed separately. Tapping mains across the street enable

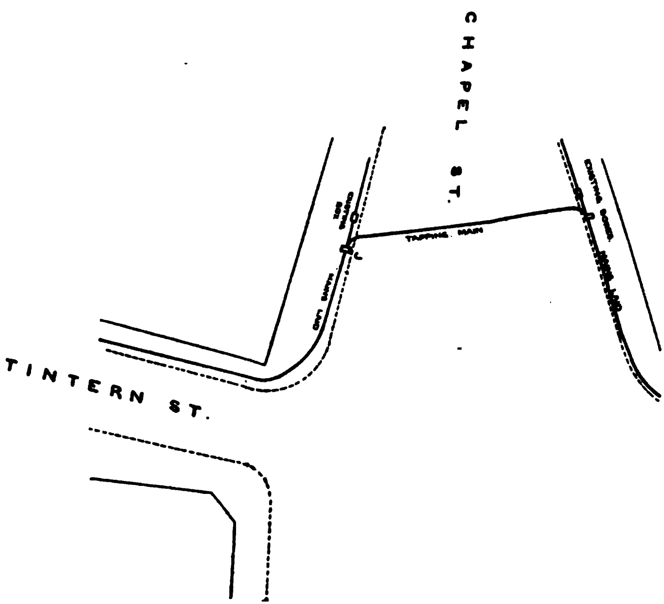


Fig. 182.

the load to be put on the lightly loaded district, so as to relieve the more heavily loaded feeder should the consumers increase more rapidly on one side than the other.

Illustrative Examples of mains and connections are given in the accompanying figures. In fig. 182 the tapping main connects the two networks on the upper and lower sides of Chapel Street. In this case the distributors are coupled.

In fig. 183 a tapping is shown connecting a feeding-point at the box marked J, to the feeder line on the lower side of Old Ford Street. In this diagram the distributors follow the same route as the feeders, but are independent of them save at the box J, where the feeder on the upper

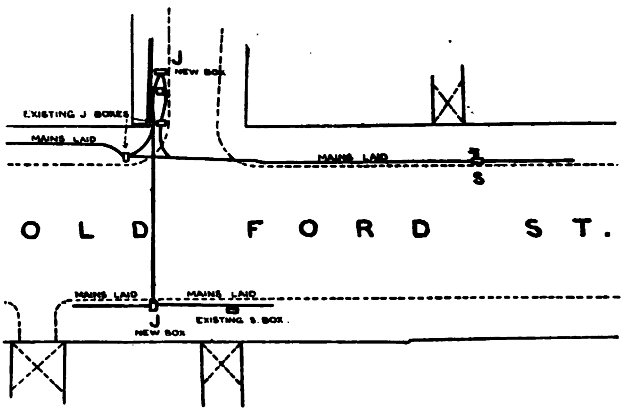


Fig. 183.

side of the street is connected to the distributors on that side. The distributors on the lower side are not shown, but run through the box marked as "existing s box."

Fig. 184 gives a common arrangement where an extension is taken off an existing run of mains. In this case, down Duncan Street feeders and distributors are run in the same trench. The feeders go into the boxes J and J, which are usually located at street corners and provide means of varying the feeder runs as required, or of extending feeders from an existing point to another further into a new district should the load centre make this change desirable. The distributors run into and through the service boxes, marked s, which are located at convenient

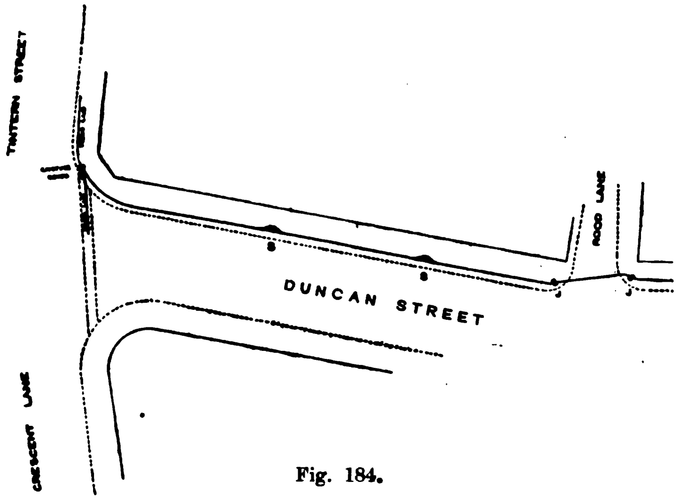


Fig. 184.

points for giving origin to service lines. Each box may take 2, 4, or 6 services. The end box supplies a service.

Other details of typical networks are shown in figs. 185 and 186. In

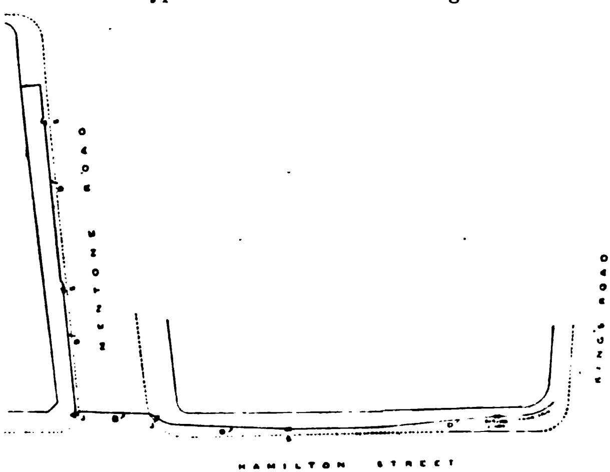


Fig. 185.

fig. 185 the length of distributor along Hamilton Street connects the existing box to the right with the junction box J, which is arranged to provide a feeder point if necessary. The distributor runs up Mentone Road to supply the service indicated. An interconnecting point is in the same way shown in fig. 186, and these examples illustrate how a network is gradually built up by the constant addition of lengths

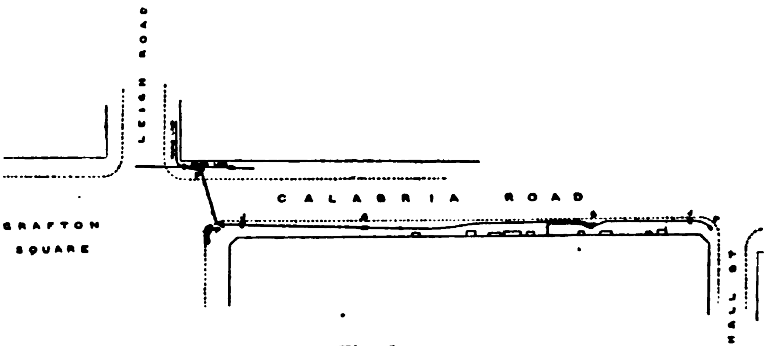


Fig. 186.

which are usually laid as consumers apply and supply is demanded along a frontage.

Fig. 187 gives the general plan of a system of mains, generating stations and feeding-points. The four generating stations are indicated by squares, and the feeding-points by circles. The latter are most numerous where the demand is dense, and scattered where it is spare. The smaller circles indicate disconnecting and testing boxes.

Regulation at the generating station requires some means whereby the pressure at the feeding-points is made known to those in charge on the switch board. These may be pilot lines or indicators. Instead of measuring the pressure at the station, which by itself is of no value for feeder regulation, the engineer must know exactly what is taking place at a point several hundred yards away, and as everything depends upon his knowledge being correct at all times, a continuous indication can alone prove satisfactory.

. 187.

[To face p. 360.

The first way that suggests itself is to measure the resistance of each feeder and set out upon each of the corresponding voltmeters a scale of ampères, or on each feeder ammeter a scale of volts, so that a co-relationship is established between the ampères flowing out on each feeder and the pressure to be impressed upon it at the station. When the current varies, the pressure is regulated so as to correspond with the current. As the impressed E.M.F. is always equal to the pressure at the feeding-point, plus current in ampères multiplied by the resistance of the feeder in ohms, and the latter product represents the pressure-drop, the pressure at the feeding-point is constant. Instead of putting the figures on the instrument dials, a table may be prepared giving volts and ampères; but by far the best way is to do as first described. It is necessary to remember that the required resistance of the feeders must not be taken by a bridge or testing set, but with the various working currents actually flowing, and a potentiometer or low reading voltmeter. What is then measured is the drop in volts, and this may be used as the product, $c \times r$, to be added to the normal supply pressure.

The second means of indicating the pressure is to bring a pair of wires back from the feeding-point to the generating station, and couple them up to a voltmeter. Such conductors are termed "pressure wires" or "pilot wires."

Compound-wound voltmeters can be substituted for pilot wires, if the latter cannot be used. In principle the compounding consists in introducing a back E.M.F. into the voltmeter circuit, or by creating a reverse magnetic field, the back E.M.F. or opposing magnetic field being proportional to the outgoing current in the feeder. The net result is that the indications give the pressure at the feeding-point.

CHAPTER XI

CONDUITS, MAINS AND BOXES

When electricity supply as a business was in its early stages, the only means by which current could be distributed was by overhead wires, as capital could not be found for expensive permanent works of an experimental character, and no powers existed whereby the streets could be opened for the purpose. A direct route to scattered consumers was provided by an aërial line, and as the power transmitted was small the engineering difficulties were easily got over. Aërial lines are not now used save in exceptional cases, but there is a growing feeling that their use should be permitted for the supply in rural districts.

Underground Mains may be divided into two classes—(*a*) those in which conduits are provided for the reception of the conductors, and (*b*) those in which cables are built in with a protecting material or laid directly in the ground. In the first class the conductors are separate from the means by which they are mechanically protected.[1] The conduit, in fact, simply forms a hole, duct, or way through which one or more cables or conductors can

[1] The various forms of cables and mains have been fully dealt with in another work in the "Specialists' Series," to which the reader is referred for such descriptions as want of space has caused to be omitted above.

be drawn when required. Built-in or buried systems do not permit of the withdrawal of the cable when once laid, nor can any increase in the number, size, or area of the conductors be effected without carrying out entirely new works similar to the first.

Subways may be taken as the type of all conduit systems. They are distinguished from conduits proper by their size, and by their not being devoted solely to electric-supply cables. In this country they are principally to be met with in the Metropolis, where they have been built and are owned by the London County Council and the Corporation of London. The cost of constructing subways is very heavy, and owing to the position in which they are laid—evidently the best place being the centre of the roadway—they do not afford such facilities as are desirable with general distribution of electricity. Theoretically, by the construction of subways a municipality does away with the periodical disturbance of the public streets, and the tunnel-like way provided underground should be a most convenient place to put pipes and cables, which are always accessible throughout their length without inconvenience to any one. Subways, although suitable for through mains or trunk lines of supply of any kind, are eminently not so for electrical-distribution conductors which have to be tapped at frequent intervals.[1] Although where they exist undertakers are forced to make use of them, the cost of mains and services works out at a higher figure than if the lines were laid under the footway on either side. In fig. 188 a cross-section of a typical London subway is given, showing the water, gas (G), telegraph (T), and pneumatic (P) pipes, and the position of the electric-cable ways (E). The connections to the

[1] *Journ. Inst. E. E.* p. 142, vol. xxiii.

surface boxes are made by means of wrought-iron barrels. Even in a subway cables have to be protected as

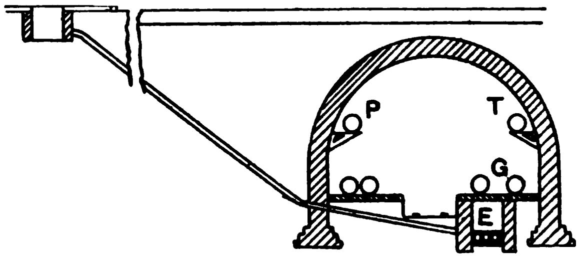


Fig. 188.

thoroughly as they are when laid by themselves in the ground.

Bare Copper Systems may be compared to an aërial system taken bodily and placed within a tunnel or trench driven or formed below ground. The two great arguments used in their favour were—firstly, the alleged economy in construction, the small cost of up-keep, it being considered that by the avoidance of perishable materials the depreciation would be a minimum; and, secondly, the readiness with which additional copper could be drawn in and the sectional area of the conductors increased as the business extended. To these claims might be added the facilities for making service connections direct to the mains at any point without cutting insulation or breaking the continuity of the conductors. On the other hand, there is the obvious risk of flooding and the liability to chemical action at the insulating supports if salt water or moisture containing alkalis is present and electrolysis is set up by leakage currents. The objections are found to be of vastly greater importance now that continuous-current supply is given with 400 to 500 volts on the outers of

a three-wire system, and experience seems likely to prove that methods quite suitable for 200 to 230 volts will lead to trouble and be subject to faults when the insulators are required to withstand double this pressure.

The patterns occurring in practice may be examined under the three heads:—(*a*) Conduit, (*b*) insulators, and (*c*) conductors. Circular pipes of earthenware or of cast iron and rectangular sectioned culverts lined with retaining walls of brick and concrete, or concrete alone, have been put down. The insulators range in form from ordinary conventional telegraph patterns supported by oak beams to carefully designed forms which are bedded on the bottom of the culvert. When the culverts are constructed of brick and concrete, the bottom is formed of concrete rendered on the inside with cement; the side walls are formed of brickwork grouted at the back with fine concrete. The top is covered with York stone or slabs of coke-breeze concrete, jointed with cement and covered with a layer of asphalt to render it waterproof (fig. 189).

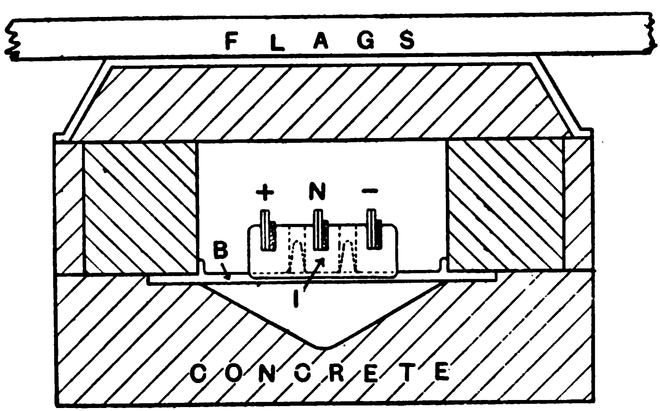
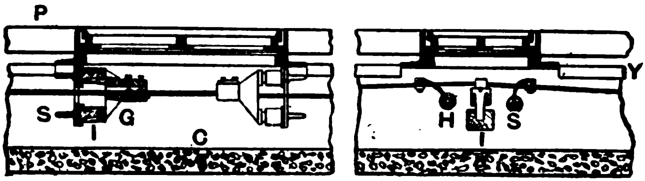


Fig. 189.

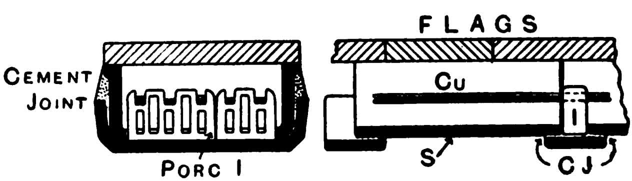
In the Crompton-Davis system copper strips are supported by glass insulators. The strip is strained at the time of drawing in, and the strain is taken by special insulators at intervals (figs. 190 and 191).



Figs. 190 and 191.

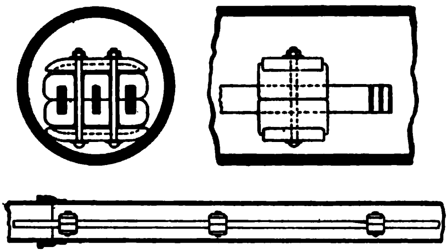
The Crompton system as now put in has straining boxes every 50 yards, and supporting boxes every 12 yards. Wood supports are not used and glass insulators are discarded. In their place brown-ware petticoat insulators are fixed on galvanized iron girders. Wood has been found to be very objectionable in underground work.

In the Kennedy system the strip lies in insulators as in fig. 192. An objection to this arrangement is the facility for moisture and drip water to form a continuous surface between the strip and the iron girder. All insulators used underground should be of the petticoat pattern, allowing water to drop clear. A modification has been introduced by Mr. Tonge, making the conduit of Doulton earthenware, when the arrangement becomes that shown in figs. 192 and 193.



Figs. 192 and 193.

Cast-iron troughs have been used for the system of mains originally laid for the St. James and Pall Mall Company in London, and as this was one of the first important examples of the kind it has been frequently and very fully described. Figs. 194, 195 and 196 show



Figs. 194, 195, and 196.

another arrangement of bare copper conductors drawn into a cast-iron pipe. The copper strips of the three conductors, two outers and a neutral, are clamped together with bolts passing through top and bottom insulators and beechwood rests, and the whole is drawn into a cast-iron pipe 8 inches in diameter as shown. Lengths up to 90 feet have been treated in this way in the St. Pancras district of London.

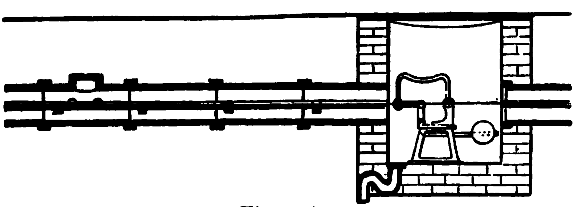


Fig. 197.

Mr. Scott has used ordinary drain-pipes for the bare copper mains at Norwich. Mr. Wilson Hartnell [1] has

[1] Patent, 16,963, 1890.

proposed to use earthenware pipes with insulating bridges resting in recesses. The bare copper strip or standard conductor is strained up by weighted levers (figs. 197, 198, and 199).

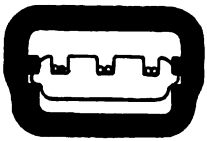


Fig. 198.

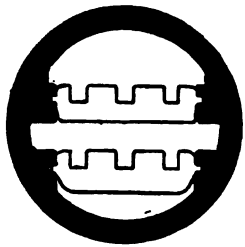


Fig. 199.

Conduits are ducts or pipes intended for the reception of insulated conductors. Wooden casing, so largely used for protecting interior or house wiring, has been employed in America to protect underground cables also. Figs. 200,

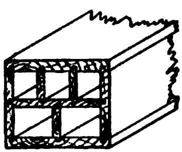


Fig. 200.

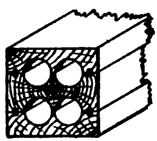


Fig. 201.

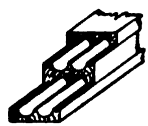


Fig. 202.

201, and 202 illustrate two of the forms used, the first being the Valentine and the second the Macdonald or Wyckoff conduit. The "Cummings" wood conduit has been used in Detroit, U.S.A., with bare copper conductors, while Mr. W. F. Taylor has devised a similar system in this country.

Wood is evidently an unsuitable material to use, and earthenware or iron (cast or wrought) has taken its place.

Cast-iron pipes similar to those used for gas and water supply, of from $1\frac{1}{2}$ to 6 or 8 in. diameter, with spigots and sockets joined together with yarn and lead, run in molten, have been more extensively used than anything else, except earthenware. The arrangement of such a system is indicated in fig. 39, where two parallel lines, one of 6 in. and one of 4 in., are provided for incandescent and arc cables respectively. At intervals boxes are inserted giving access to the pipe line. These may take the form shown in plan in figs. 203, 204, and 205, being a

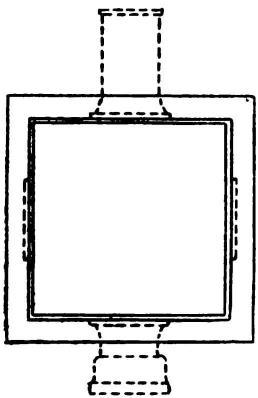


Fig. 203.

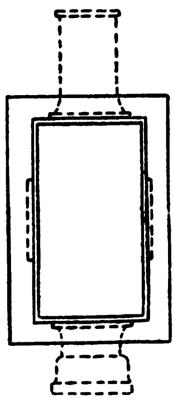


Fig. 204.

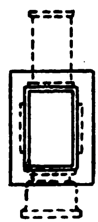


Fig. 205.

cast-iron box with or without a bottom, and with holes on each side and end, to which blanking-off pieces or flanged outlets are bolted. The surface frame is usually separate from the box, to enable it to be fixed flush with the pavement level. Surface covers of cast-iron filled in with concrete or wood blocks form the top lid of the box, an inner lid of wood being provided to prevent the cables bending and touching the upper cover.

This construction maintains continuous electrical connection throughout the system of conduits, and if the surface frame be packed up with semi-insulating material there is little risk of a fault to earth charging the pavement or ground near the box, and thereby causing the passers-by to receive unpleasant, if not dangerous, shocks.

The only important variation from circular cast-iron pipes was the Johnstone conduit, of which a considerable amount was laid at Portsmouth. This consisted of a cast-iron trough and lid with vertical partitions dividing the space into ducts. A complete system of manholes and outlets in cast iron throughout was included in the system, which, however, has not extended in this country.

Wrought-iron pipes laid in concrete or bitumen have been largely used in America, where the principle of "one duct one cable" was followed from the first as far as circumstances permitted. The most important example in this country is the work done for the "City" and "County" (London) Companies. With a view to reduce the cost of the material, several American engineers adopted sheet iron for the pipes, relying upon the cement bed in which they were laid to retain the form given them.

A conduit formed of paper tubes set in a wooden containing trough of square section, with the spaces between the tubes filled up with asphalt, has been used on a small scale in some American cities. A somewhat similar arrangement has been adopted in this country, under the name of the Raworth-Callender-Webber conduit,[1] consisting of paper-lined ways bedded in bitumen and laid in cast-iron troughs with separate cast-iron jointing pieces, the top being protected by cast-iron covers, laid over the trough, as shown in fig. 206. The difficulty of dealing

[1] *Journ. Inst. E. E.* p. 171, vol. xxiii. Patent No. 3,239, Feb. 23rd, 1891.

with slight divergences from the straight line and with bends, however, in the tubes is a great objection, and the

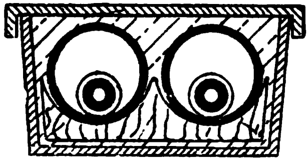


Fig. 206.

durability of paper where it is subjected to the abrasive action of cables being drawn in and out is questionable; but it might be possible under favourable circumstances to employ bare copper conductors in the tubes, should it be found that the paper, when impregnated with compound, and protected by the bitumen setting, is a sufficiently good insulator under low electrical pressures.

A fibre conduit has lately been introduced from America. This is a kind of hard fibre or papier-maché, and it is claimed that it is cheap to instal owing to its light weight and simplicity of jointing, 6,000 ft. having been laid by one man in 10 hours. It has a high insulation, ½ in. in thickness, withstanding 25,000 alternating. It is water-tight and non-inflammable when laid, and can be set in concrete with spigot and socket joints, or laid directly in the ground with screwed joints.[1]

An impregnated paper tube, capable of being used alone or with a brass or iron armouring, has been in service in America for some years for interior wiring, under the name of "interior conduit," and is now finding some favour

[1] Manchester has laid down some thirty miles of this tube (contractors, The Key Engineering Company, Ltd.), which has the advantage of being free from glazing or cement jointing, both of which are said to give trouble at times with lead-covered cables.

in this country. It is quite possible to utilize this for underground work, much in the same manner as the methods described above, or to lay the armoured class of tube direct in the ground.

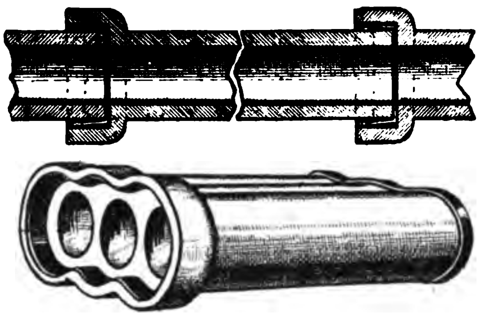
Stoneware pipes of circular section have already been alluded to in connection with bare copper mains. They form a serviceable means of protecting insulated cables on a drawn-in system, as they resist acid if properly glazed or vitrified, and are non-porous. Being made in large quantities, they are cheap and can be laid at a small cost, but being in comparatively short lengths and joined with cement, it cannot be said that they possess great mechanical strength, such as would be desirable in the event of subsidence in the ground below them. They, in common with earthenware conduits, have an advantage in their insulating and fire-proof qualities; in the event of a fault or burn-out occurring, the arc cannot damage neighbouring gas pipes or telegraph wires, accidents of which kind have taken place more than once.

A conduit which has been largely used in the City of London consists of hexagonal stoneware ducts bedded in concrete with a paper guide piece at the joints. The National Telephone Company for some time made a cement conduit in large quantities.

Stoneware and earthenware conduits are made by Doulton, Albion Clay Company (figs. 207 and 208), and Stiff, in which a number of ducts are provided in a block, but it is difficult in a congested sub-soil to find room for a rectangular-sectioned body of considerable width, although, if space is available and the foundation is good, such conduits are serviceable and durable. They are made with varying sections and sizes of ducts, to suit the local conditions.

Several large schemes of tramway feeders have been carried out with stoneware pipes of circular section provided with ordinary spigots and sockets, but with the inside edge of the spigot rounded off, cement-jointed, and laid on a bed of concrete with a face each way towards brick drawing-in boxes provided with bell-mouths.

Stoneware conduits arranged with circular ducts similar to drain pipes, but with rounded ends internally, are being largely used, as they admit of cables being drawn



Figs. 207 and 208.—Spigot and socket earthenware pipe conduits for cables on the draw-in system.

in easily and offer little resistance. They are jointed with spigot and socket ends, and in many instances are fitted with Stanford or self-centring joints, the composition linings being fitted to secure absolute alignment without the aid of mandrils, and permitting their being laid rapidly, the ground being filled in at once.

An ingenious mode of constructing conduits with multiple ducts has been tried which seems to promise well where a number have to be laid, and the work is of

sufficient magnitude to justify a heavy bed of concrete. Hollow mandrils are coated with a wax preparation and set in position in the trench. The space is then filled in solid with concrete, and this is allowed to set. Steam is then admitted to the interior of the mandrils, causing the wax to soften, and permitting the mandrils to be withdrawn, leaving circular ducts in the monolithic mass. The wax is of assistance in leaving a smooth and lubricated surface against which to draw the cables in later.[1]

Insulated Cables are used on drawn-in and solid systems. They usually consist of conductors formed of stranded copper wires surrounded by a layer of solid insulating material protected by lead sheathing if hygroscopic, or by a covering of tape, and (in the latter case) over all by braiding impregnated with a preservative mixture of such substances as pitch and Stockholm tar. The conductor is formed of a number of suitable-sized wires stranded together for the sake of flexibility, the section being circular, so that for a given perimeter the largest possible area shall be enclosed. Each wire must be large enough to resist the mechanical stresses in laying up and coiling after completion of the cable, but not so large that the cable cannot be coiled upon drums for transport. Copper for wire is now refined by electrolytic methods in large quantities, and is seldom much below the quality that in Matthiessen's time was regarded as "pure copper."

Indiarubber is an excellent insulator when of good quality and vulcanized, but, owing to the reckless manner in which the gum trees that yield it have been treated, and the demand created by its extensive use, it is now a difficult matter to procure the best and most suitable

[1] Messrs. Berry, Skinner & Co. are the representatives of this system.

rubber, and the price is rising rapidly. Pure Para rubber has great elasticity, and a high tensile strength, the strip made from it after washing and mastication giving a high specific insulation resistance, but it is liable to undergo decomposition when exposed to light and heat, and consequently perishes. By mixing sulphur with rubber, and exposing the mixture to a temperature of 250° F. to 300° F. for a period varying from several minutes to an hour, depending upon the size and quality, the rubber is "vulcanized" and becomes chemically stable. The sulphur combines with the organic substances which would otherwise lead to chemical change, and rubber so treated can be relied upon if proper precautions be afterwards taken to protect it from the atmosphere and from excessive mechanical strain.

Mixtures of rubber with materials such as French chalk have been proposed by different inventors. Okonite and similar proprietary compounds resemble rubber in mechanical properties, while it is claimed that they possess the advantage of greater durability.

Bitumen, a mineral product found in asphaltic rock and obtained in large quantities from the pitch lakes in Trinidad, is allied to petroleum, naphtha, and shale oils. It is when refined and in a pure state an excellent insulator, and is used as a dielectric in Callender and other cables, such as "Dialite," after having been mixed with sulphur and subjected to a process analogous to vulcanization. Cables insulated with vulcanized bitumen may be drawn into conduits or laid direct in the ground with suitable mechanical protection. Probably it is at its best if laid solid in the manner hereafter described.

Paper is now one of the most common of insulating materials. The principal distinction between different

classes of insulated cables is one drawn from the effect of moisture upon the material employed as dielectric. Rubber and its compounds being waterproof, gives a non-hygroscopic dielectric, and does not require any direct protection from damp, whereas those cables in which the insulating material consists of a layer of organic fibre freed from uncombined moisture by exposure to a high temperature during manufacture, and then impregnated with mineral oils, are prone to re-absorb aqueous vapour, and being therefore hygroscopic, have to be waterproofed by a continuous metallic sheathing of lead. Diatrine is a very tenacious and sticky compound used to impregnate paper cables and to fill joint-boxes. Compound insulated cables consist of a close-grained Manilla paper, impregnated with hydro-carbon oils next the copper. This is sometimes but not necessarily followed by a layer of fibre applied as a fine yarn, laid up in a spiral, and treated with a bituminous or resinous compound. The lead sheathing is then applied under a pressure of about thirteen tons per square inch, the density of the metal rising to 11·6 instead of 11·35, the usual density. The pores of the paper are filled with the resinous oils, and a jelly of semi-solid material is held in contact with the paper by the lapped fibre. The cables of the Western Electric Company made under the Fowler-Waring patents, were formerly of this class.

The process of manufacture of simple paper cables is as follows. The stranded copper core is covered with strips or tapes of specially-prepared Manilla paper, wound on so that they break joint, and lapped until the required thickness of insulation is reached. The covered core is then placed in a hot-air oven, and left for several hours for the moisture in the paper to be driven off. It is

then placed in a tank of hot resin oil, and, after impregnation, is run off through a hydraulic lead press, which covers the insulation with a closely-fitting sheath of dense lead. If the operation is properly conducted, the sheathing is free from pinholes, and the pores of the paper and all interstices are filled with the oil. A braiding or armouring is then put over the lead, completing the cable. This is the process adopted by the British and Helsby Cable Company, Ltd., and many other makers.

It is claimed for impregnated cables that they are more durable than others, owing to the chemical stability of the materials used. They give a high disruptive strength, but have to be carefully guarded against access of moisture, and are not so flexible as others, while everything depends upon the integrity of the lead sheathing.

Armoured cables laid direct in the ground or drawn into earthenware conduits merely to save the inconvenience of frequently disturbing the public thoroughfares are satisfying most of the requirements of general supply; the tendency being to approach the methods of distributing gas and water so far as the character of electrical work will permit.

Concentric cables with two conductors (figs. 212 and 213) are frequently used for two-wire continuous-current feeders and almost universally for high-pressure alternating work, while triple concentrics (figs. 209 and 210) are generally adopted for alternating-current distribution on the three-wire system. The outermost conductor is the neutral, and is of half the sectional area of either of the other two. Twin conductors of the type shown in fig. 211 are very suitable for arc circuits. For poly-phase working three-core cables, figs. 215 and 216 are universally employed. Similar cables are used as an alternative to triple

concentrics for low-pressure distributors, and have the advantage that services can be taken off without inter-

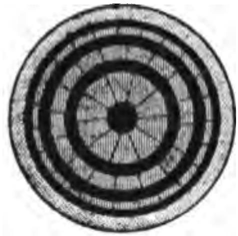


Fig. 209.

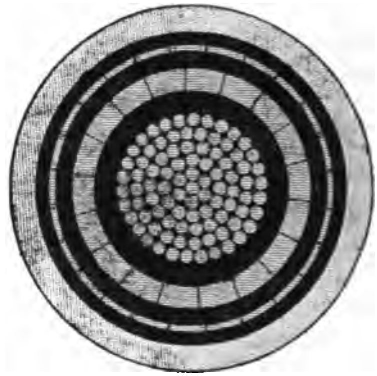


Fig. 210.

Figs. 209 and 210.—Full-size sections of triple concentric low-tension distributing lead-sheathed cables.

Fig. 211.

Fig. 212.

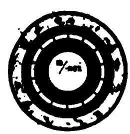


Fig. 213.

Fig. 214.

Fig. 215.

Fig. 216.

Fig. 211.—Twin conductor. Figs. 212 and 213.—Double concentric conductors. Fig. 214.—Triple concentric distributing cable with neutral of equal area. Figs. 215 and 216.—3-core cables.

fering with the supply and at a less cost than with the latter. Figs. 211, 212, 213, 214, 215, and 216 are half scale of cables largely in use on town networks, paper insulated and lead sheathed.

Solid Systems are those in which the cables are laid in a semi-insulating material. In the Callender System the cables are insulated with refined vulcanized bitumen and protected by braiding. The cables are embedded in crude bitumen poured round them in a molten state and allowed

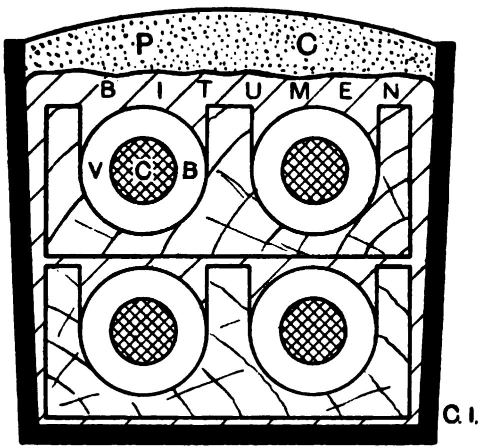
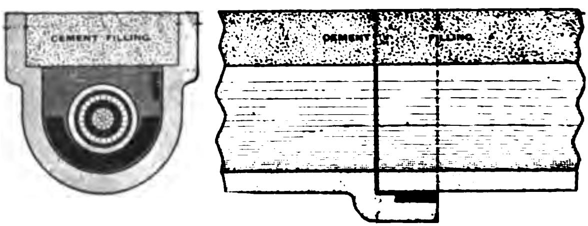


Fig. 217.

to set. In laying, cast-iron troughs are laid flat and solid in the trenches, rough corners and sharp bends being avoided as far as possible. The lengths of troughing are connected one with the other by means of countersunk bolts and nuts, with the nuts outside. A wooden bridge-piece, to support the cables, is placed at the junction of troughs, and troughing is prepared for cables by pouring in a thin layer of bitumen lining, and setting the bridges in as long

lengths as possible. The bitumen insulated cables themselves are carefully protected from damp. Upon this simple precaution depends much of the success of the solid system. They are laid parallel with the sides of the trough, but not touching it at any point. Fig. 217 gives a sectional view of two pairs of feeders laid on the solid system in a cast-iron trough.

Solid systems aim at embedding the cable in a homogeneous mass of bitumen or pitch. If carefully laid so as to ensure this being the case throughout, they are certainly efficacious, but it must not be taken for granted that the requirement is fulfilled. There is a tendency to revert to the laying of armoured mains directly in the



Figs. 218 and 219.—Sykes' spigot and socket trough for cables laid on solid system.

ground. It is a simple matter to be certain that a cable is armoured continuously throughout its length, and from experience there does not seem to be any reason to anticipate that in most natural soils armouring will suffer through contact with them. On the other hand, solid systems, unless continuous or bedded in concrete, may be damaged by heavy traffic causing a springing action at the joints of the troughs tending to cut through the lead and breaking up the composition filling.

Stoneware troughs are now being generally substituted for wood or cast iron,[1] except in the case of extra high-pressure mains in which case the metallic envelope of the cast iron is an advantage. The troughs are made in a square or U-shaped section, and are covered by blue brick tile or a filling of three parts sand and one part Portland cement. Butt-ended troughs were formerly used. These are giving place to spigot and socket joints, figs. 218 and 219, which permit of the various lengths being more securely jointed together. Fig. 220 shows a U-shaped trough with its cover and Ruthven-Murray

Fig. 220.

Fig. 221.

Fig. 222.

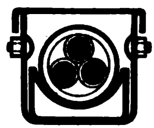


Fig. 223.

Figs. 220, 221, 222, and 223.—Sections of mains on solid system in earthenware, Howard asphalte, cast-iron and pressed steel troughs.

supporting bridge. This is a steel strip 1 inch wide and ·03 inch thick, buckled over at right angles to its length, making an excellent means of holding the cable in position.

Asphaltic concrete protected by a thin steel sheeting externally has been used in the Howard system (fig. 221). The cables are laid directly on the bottom, and after filling up the interstices with bitumen, a mixture of

[1] "In our early underground work in Glasgow we started by laying lead-sheathed cables in iron troughs, but we are now definitely convinced that this is quite a mistake."—W. W. Lackie, *Journ. Inst. E. E.*, p. 146, vol. xxxv., February, 1905.

granite chippings and bitumen is poured on and moulded to form a cover. The lengths are softened at the ends by means of a hot iron and afterwards pressured together, making a continuous run, thus dispensing with joints. As the material itself is an insulator, it is claimed that the system possesses special immunity from trouble.

To the same scale as the two preceding figures, figs. 222 and 223 show solid mains in cast-iron and pressed steel troughs. Portland cement and sand set round a framework of expanded metal form the Concrete Construction Company's trough.

Coupling and Switch-boxes are used to connect the various cables forming a system of feeders and distributors together at different points, to which access is provided for the purpose of testing and isolating the different conductors in the event of repairs or other work being taken. At feeding-points the feeders have to be connected to the distributing system, and such feeding-boxes are important centres in relation to the districts supplied from them.

Street boxes have to be carefully protected against the influx of gas and water, and in addition precautions have to be taken against a slow process of electrolysis that has been found to take place at the ends of cables where they are led into such boxes. Explosions have occurred where to all appearance the rubber packing or gland rings have been perfectly tight, or where a compound has been used to seal up the cables at the points of entry. Gas troubles are most effectually guarded against by efficient ventilation of all conduits and the most perfect sealing up of all closed boxes. Moisture, present in the air at the time of opening a box and imprisoned by the same being closed, is readily dealt with by a desiccating agent being placed in

each box and chamber, and this should be renewed each time the box is opened. Water should be excluded by great regard being paid to all glands and packing rings, but as even the greatest care cannot entirely prevent condensation and access of moisture in small quantities, the design should allow of all such moisture being drained away from the live metal parts.

The early Edison boxes are good examples of the class, as they provided means for inserting fuses and coupling distributors up as desired. A typical arrangement of more recent date is shown in fig. 224; this is the pillar connector of Mr. Wordingham. The cable ends are provided with sockets which are bolted on to the rings carried by the pillar, and insulated by the ring insulators shown. The funnel is a drip-guard to catch falling moisture and conduct it away from the electrical parts.

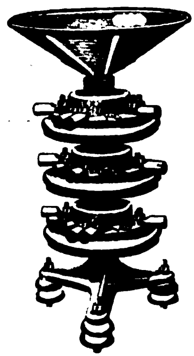
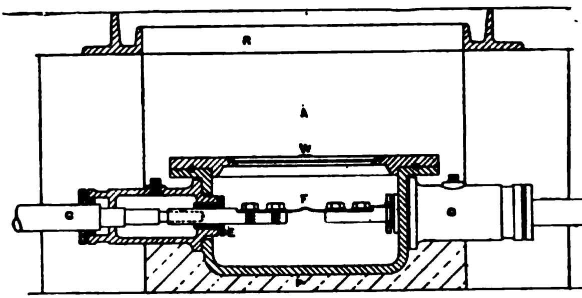
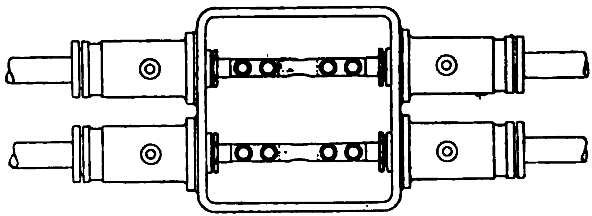


Fig. 224.

Low Tension Boxes are usually placed at the junction of separate networks, and frequently contain fuses. The intention is that should a serious fault occur on any one, that on which it exists should be isolated from those surrounding it, and to which it is connected under normal circumstances.

A box is illustrated in figs. 225 and 226, of the type suitable for fibre impregnated cables. It consists of a cast-iron body resting on a concrete bottom, P, with a brickwork setting, carrying a road frame, R, into which a surface cover fits on the pavement level. An air space, A, is thus formed above the box. The cables, C, are brought into the box through sealed terminal glands, G, filled with a bitumen insulating compound poured in hot through a hole which is afterwards plugged up. A gun-metal terminal, sweated on to the end of each of the cables, passes through an





Figs. 225 and 226.—Fuse-box on distributing mains for sectioning, with compound glands on lead sheathing.

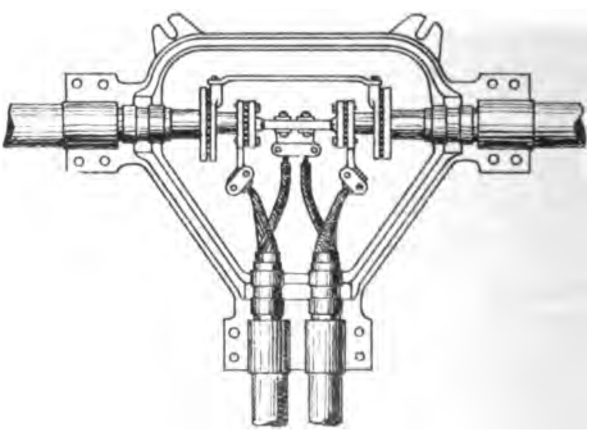


Fig. 227.—Double Tee-joint box on triple concentric distributing main, with compound glands on lead sheathing.

ebonite gland, E. The cover has a glass window, W, and is packed with an indiarubber ring. The surface cover can be readily removed at any time, as it is not caulked down, but merely secured against mischievous interference by requiring some special appliance to lift it; the condition of the fuses, therefore, can be easily inspected. Such an arrangement gives high insulation as the live metal is in contact with ebonite and air only. For networking solidly through from main to main buried joint boxes of the type shown in fig. 227 are often employed. These are filled up solid with compound. On long feeders or distributors it is necessary

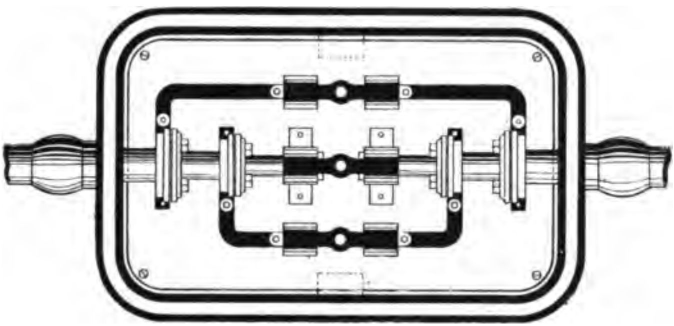
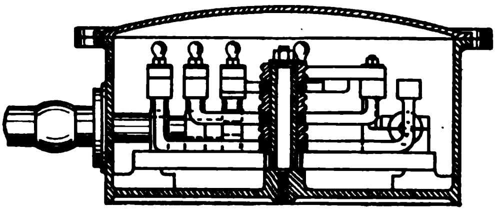


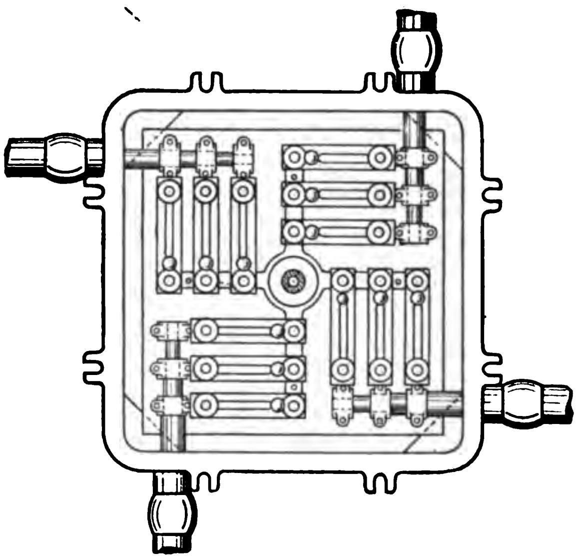
Fig. 228.—Disconnecting box on triple concentric distributing main, with sweating glands on lead sheathing.

to provide means of splitting them up into sections. Fig. 228 is a plan of a three-wire box with removable links. These have insulated handles which screw into them. The lead-sheathed cable in this instance is plumber-wiped jointed on to the gun-metal glands at each end of the box. The flanged terminals are excellent for making connection, but take up more room than the screw pattern depicted in figs. 229 and 230.

For the purpose of connecting distributors together, it is now the practice to employ four-way boxes which provide means of readily disconnecting any length of main without interfering with the supply on the other sections. A pattern which the authors have found very convenient is shown in figs. 229 and 230. On an ambroin or other insulating base grip terminals are fixed to terminate the cables. From a central insulated bolt spiders are rigidly held by porcelain insulators, the cable terminals and the spider ends being connected by sliding switch pieces.

Similar boxes with a different scheme of connections can be used, as shown in fig. 231, to give origin to two-wire systems from a three-wire, or to enable these to be coupled together. In the diagram the arrangements of a box devised by the authors is shown where at each





Figs. 229 and 230.—Four-way disconnecting box for coupling distributing network, with sweating glands on lead sheathing.

end a triple concentric cable on the three-wire system is joined to terminals, and by means of the bars, double concentric cables on the two-wire system may be connected to either side of the three-wire system at will.

Callender Boxes on the solid system rely upon bitumen sealing for water tightness where the cables enter and leave. The feeders and distributors are terminated by being sweated into copper lugs, and the joint thus made is perfectly insulated with bitite, all tape and yarn being cut back to the outside of the box. The insulated joint is finally dipped in special insulating wax compound, which preserves it against moisture and reduces surface leakage. Copper connecting bars of ample section are fixed and brought into intimate contact with the projecting portions of the lugs by means of phosphor-bronze set-screws.

Before being placed in the ground the boxes are boiled in fine bitumen, in order to preserve the iron and ensure a water-tight joint between the bitumen and the iron at all points of contact. The inside of the box on the side where the cables enter is run solid for a thickness of about ½ in.,

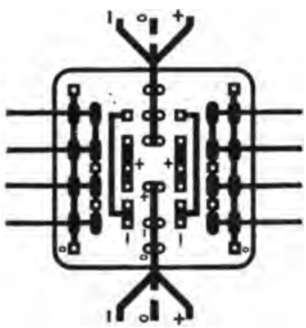
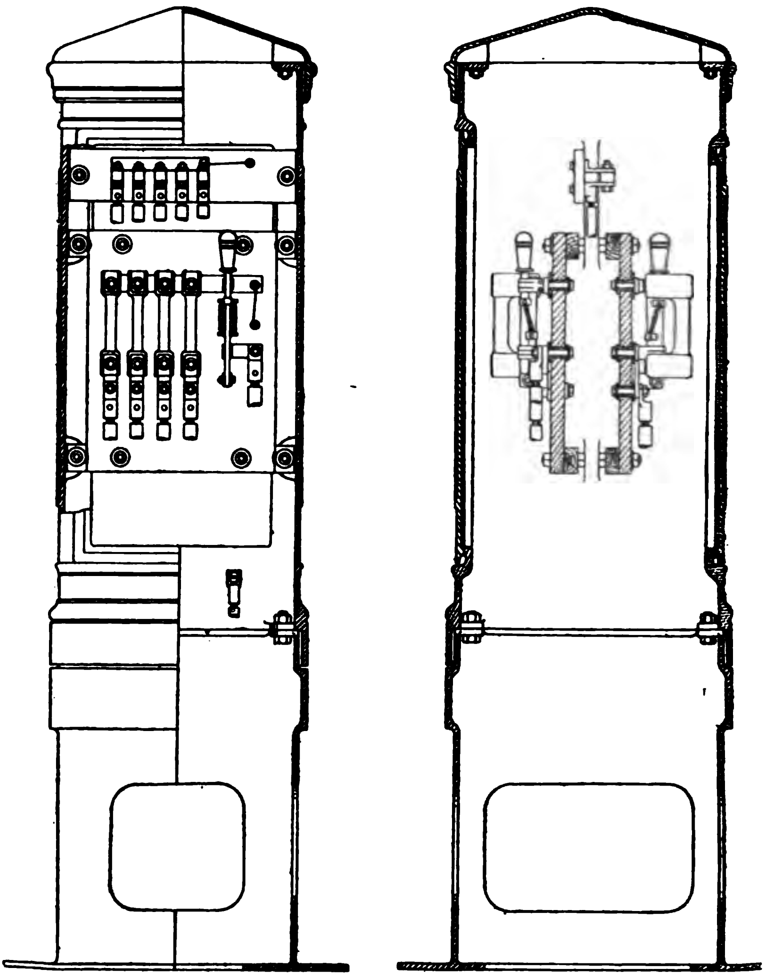


Fig. 231.—Diagram of transfer-box for connecting three-wire to two-wire distributing system.

in order to prevent leakage of water into the box from the outside. The cover is made water-tight by an indiarubber packing-ring, and this is fastened with indiarubber solution to the lid. The lid is held in position by a cross-bar resting at one end against a projecting piece on the inside of the box, and at the other against a removable pin. It can be easily removed when it is necessary to get at the connections. All the boxes have a surface cover, so that they are always accessible without raising the pavement.

Feeder Pillars are being largely adopted to eliminate the difficulties which must pertain to electrical connections below ground level. By bringing the cables up into a cast-iron pillar and fixing all instruments, switches and fuses on a vertical marble or slate slab, many advantages are attained, such as accessibility at all times, elimination of risk

of flooding and less interference with the public way. The pillars contain what is practically a switch-board of the sub-station type, and per-



Figs. 232 and 233.—Feeder-pillar for connecting feeders to distributing mains at feeding-point.

mit of the most suitable and safe pattern of apparatus being fixed. A typical example is given in figs. 232 and 233.

Insulation becomes very important on h.t. systems; street boxes being notoriously liable to dampness. Mr. Bowden devised an arrangement years ago for coupling h.t. conductors with rubber cups for insulation.

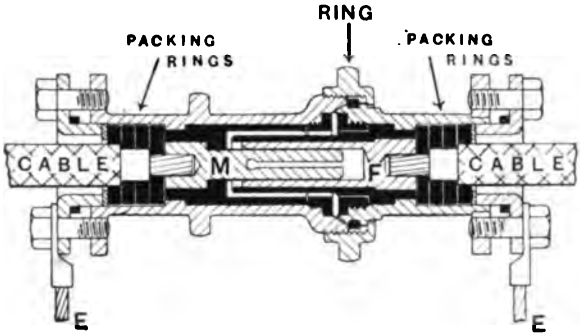


Fig 234.—High-tension cable coupling.

Mr. L. Penson developed this device as shown in fig. 234. Such devices are merely connectors, and are now only used for temporary arrangements.

High-tension Street Boxes are generally similar in principle to those already illustrated and described, but are larger owing to the necessity of providing ample insulation between the poles and of separating those parts which have a pressure difference between them of, say, 2,000 volts. For the purpose of illustrating one type we will take that shown in figs. 235 and 236. The cast-iron containing tank is provided

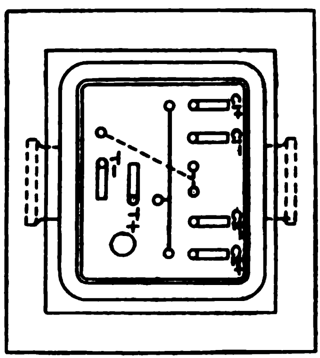


Fig. 235.—Plan of h.t. fuse and switch-box.

with connections to join on to a pipe line as shown in general plan in fig. 235. The main cable comes into the terminals C_1 + and C_1 — and goes out from terminals C_2 + C_2—, while the tapping or transformer or sub-main is joined up to T + and T —. Fig. 236 gives a general

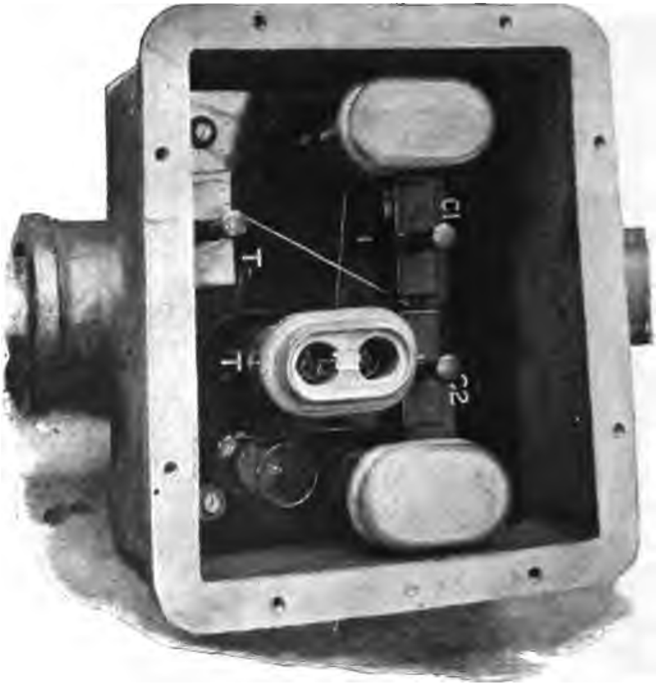


Fig. 236.—High-tension fuse and switch box.

view of the box with plugs in on the pole connected to the outer of the concentric mains and oil fuses (of the type described in Chapter on "Switch Gear") on the inner or insulated pole. A guard-slate protects the live metal work, and a glass tube contains calcium chloride for drying the enclosed air.

Services are lines connecting the ends of the wiring on the premises of consumers with the distributing mains laid in a public thoroughfare (fig. 237). A service line is usually laid for supply to each individual consumer, and forms the last connecting link of the chain of appliances between the generating station and the user that is under the supervision of, and owned by, the undertakers. Although when regarded as part of an intricate system they are of comparative insignificance, ex-

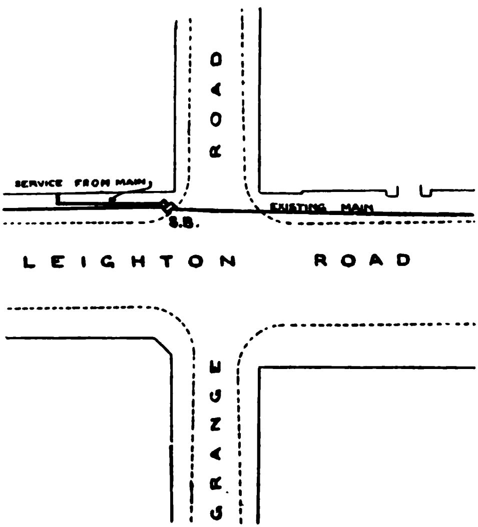


Fig. 237.—Service connected to distributing main.

perience in the past has proved that numerous troubles are likely to arise with services that are not exactly suited to the requirements of the district or the network to which they are connected. This in part arises from the fact that whereas gas and water services may go wrong without materially inconveniencing any one except the consumers supplied through them, an electric service, if it develops a fault, will probably be the means of interfering with the efficient supply from the distributor to which it is connected.

In provisional orders undertakers are bound to lay services suitable for supplying the maximum power applied for by any consumer whose premises are situate within fifty yards of a distributor upon being required to do so by him. The undertakers bear the cost of the service

laid in the public way, but the consumer may be called upon to pay for the cables where they are laid upon his property or in his possession, or where the premises are more than twenty yards away from the main he can also be charged for such length of the service as exceeds this distance. Should the consumer increase his demand or the maximum power required, then he may be charged with the cost of altering the service, and one month's notice may be required before the alteration is completed. The pressure at which supply is given on consumer's premises may not exceed two hundred and fifty volts at any pair of terminals. As service boxes are usually placed every 25 yards along distributors, services do not generally exceed a few yards in length. In cases where the joints are made on the mains and the service cables taken off directly, the length is less than where boxes are provided, but the great advantage of being able to disconnect at any time makes up for the extra length of cable required.

The size of a service is fixed by considerations of mechanical strength and pressure-drop. The best course is to lay cables that possess the desired mechanical strength and will give rise to practically no pressure drop. Thus $\frac{7}{16}$ is the smallest cable of any use. $\frac{19}{18}$, $\frac{19}{16}$, and $\frac{19}{14}$ are sizes that find favour, but after all there is much to be said for the adoption of one standard size. In some districts, for example, all services are $\frac{19}{14}$ concentric armoured cable, and it is claimed that a saving is effected by having to stock only one size of fittings.

To avoid trouble there should be a maximum limit fixed as to the current supplied through any one service. This is especially important on three- and five-wire systems, as the balancing problem is always present, and to secure good regulation it is not merely sufficient that the number of lamps on each side should be approximately equal, but the load must come on about the same time—that is to say, that the class of consumers should be balanced as well as the demand. By splitting up the wiring in large hotels, shops, offices, residential mansions, and places of amusement, and placing half on each side, this condition is met as it can be in no other way.

Whatever the limits of current may be, care should be taken that the wiring supplied at one pair of terminals be quite distinct from all other wiring, and no cross connections or paralleling inside premises should be permitted.

If three-wire services be taken from the three street conductors and led-in in the customary manner, the area of the copper in each should be the same. When this is done the interior wiring must be on two separate circuits throughout, but three-wire meters may be then

employed, provided that the system is reduced to two-wire before connecting to the consumer's terminals, otherwise two separate services are taken in, as shown in fig. 238.

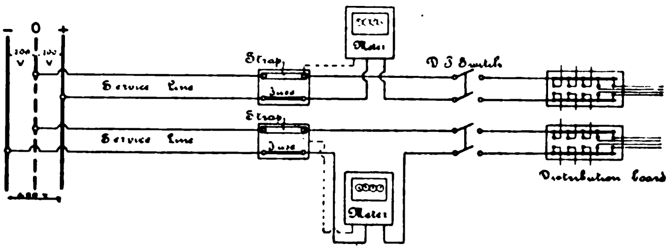


Fig. 238.—Connection of services and meters to large installation from three-wire distributor.

Service Boxes allow services to be supplied by a distributor. Some engineers consider it is desirable to get rid altogether of distribution and service boxes, which become localities in which coal gas can collect, and occasionally explode. In laying down the secondary distribution system by means of lead-covered and armoured triple concentric cable

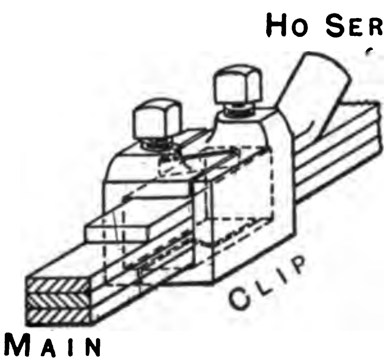


Fig. 239.

by far the best plan is to make the proper connection with a service main to each house at the time that the cable is laid, and to have this joint entirely sealed up in lead, making use of no junction box at all, or at most, of a right-angle iron sleeve to mechanically protect the joint. The service main can then be taken into each shop or house and

connected up to the consumer's terminals, whether the building takes light or not. In the central portions of a town it is only a question of

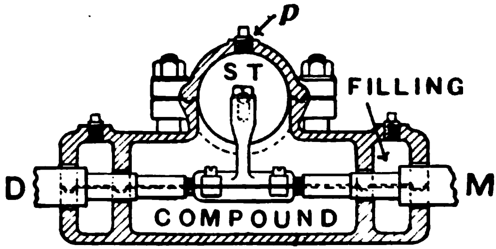
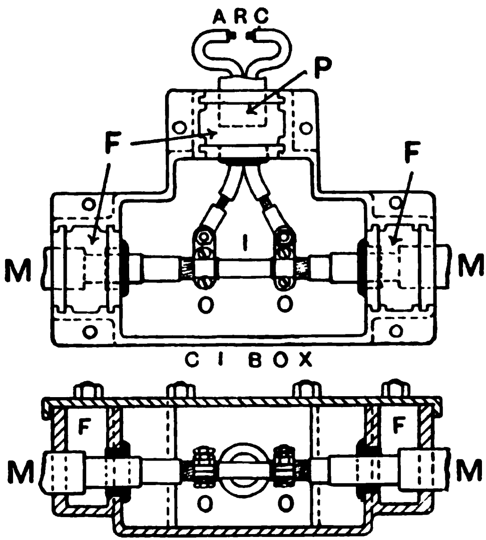


Fig. 240.

time for each shop or house to take the current, and it saves expense to make this joint in the first instance.[1]



Figs. 241 and 242.

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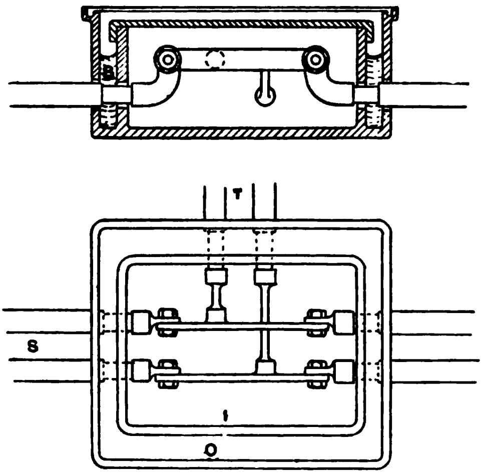
[1] Prof. J. A. Fleming, *Cantor Lecture IV.*, Society of Arts, February 10th, 1896. This, we are informed, has actually been done in High Street, Southampton.

On bare copper systems services are readily connected to the distributors, as there is no insulation to cut through. A clip such as is shown in fig. 239 may be used to connect the main and house service. With non-concentric cables having hygroscopic dielectric, the joint is sealed up with compound, the box being merely a cast-iron shell to afford mechanical protection to the joint. One pattern of joint-service box is shown in fig. 240. No fuse is included. D M is the distributing main, S T the service terminal, and *p* a plug hole to enable the interior of the box to be filled with hot insulating compound. Another pattern



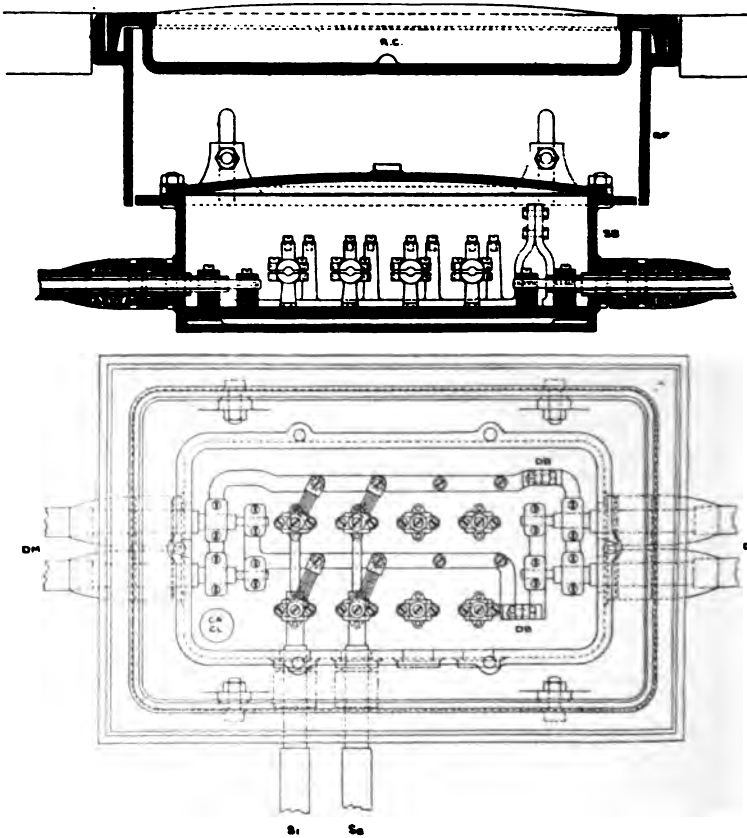
Figs. 243 and 244.

of the same class of box is illustrated in figs. 241 and 242, this being arranged for the connection of arc lamps in series on the outer of a concentric cable system, the inner of which forms the return conductor from the last arc lamp of the series to the works.

Another box in which the cables are sealed in with compound is shown in figs. 243 and 244; the cables, however, are not hygroscopic, being insulated with vulcanized bitumen. Two covers are provided, the inner being sealed in position by molten compound being poured over it; the outer is then put on and the whole box buried. The foregoing boxes are not open to inspection, but serve as mechanical joints rather than as boxes proper.

[1] The particular pattern shown was designed by Mr. B. H. Jenkinson.

In figs. 245 and 246 a detailed scale drawing is given of a service box designed to take four services and through distributors, in this case a pair of $1\frac{2}{4}$ concentric cables in parallel. The top surface or road



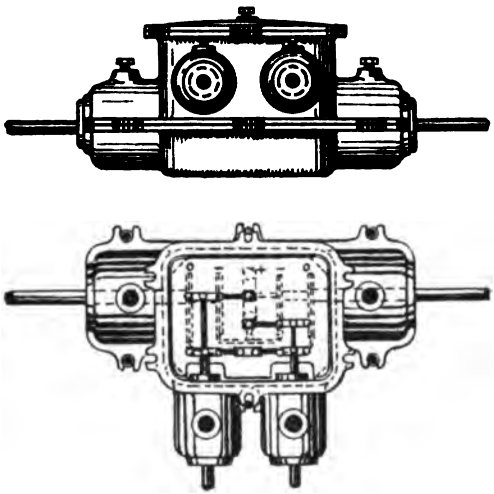
Figs. 245 and 246.—Inspectional street-house fuse and service box.

frame, R F, is separate from the lower portion, S B, so as to be adjustable to the pavement level. The distributors are cut and connected to terminals at the end of bus bars from which pillar terminals rise up, fitted with screws at the top to secure fuses. Similar pillar

terminals bolted to the fibre base are provided for the service cables as shown. The continuity of the distributors can be broken in each box at the disconnecting bar, D B. Glands fitted with indiarubber packing-rings grip the cables and make a water-tight joint at the point of entrance.

The pattern of fuses shown was first designed and used by the authors in 1895, but has since been largely adopted and is now listed by many makers of cut-outs and cable fittings.

Figs. 247 and 248 show a very useful form of house-service box for

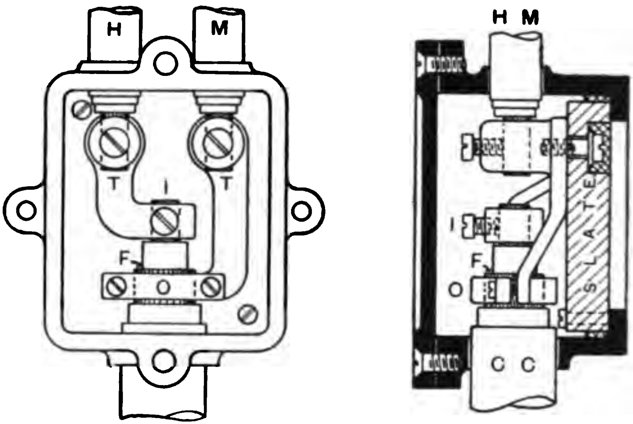


Figs. 247 and 248.—Buried house service and fuse box for three-core or triple-concentric distributors, with compound glands on the lead sheathing.

insertion on three-wire systems. It enables the services to be taken off either two-wire, on either side of the system, or three-wire, and, if desired, fuses can be inserted between the main and the service end.

THE HOUSE END of a service is connected to the consumer's wiring in a junction box of simple character. If fuses are inserted at the junction of the service and distributor this box may consist only of two pairs of terminals. Should the service line be concentric cable, then the arrangement depicted in figs. 249 and 250 might be used, which is

typical of most of the boxes actually employed. C C is the concentric cable forming the service, O the outer terminal and I the inner; a



Figs. 249 and 250.

ferrule, F, is placed below the outer conductor to enable O to be screwed hard down; the terminals, T T, take the house mains, H M.

Where fuses are not inserted at the outer end of the service the terminal box must be arranged to take them on the inner end. The Reason Company's pattern of service end and fuse box for hygroscopic cable is shown perspectively in fig. 251, and it may be noted that the

Fig. 251.

service may come in on either side of the box, and that only one fuse cover can be raised at a time, while the bottom chamber seals off the insulation.

The responsibility of the undertakers ends at the meters. An arrangement of consumer's junction box, C J B, meters, &c., is given

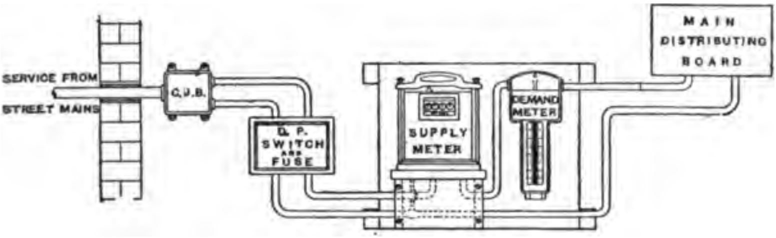


Fig. 252.

by the diagram, fig. 252, which includes the wiring of a watt-hour meter and indicator. This arrangement is preferred by the Fire Insurance Companies, but that shown in fig. 253 is generally specified by engineers. Beyond the meters the work is done by the

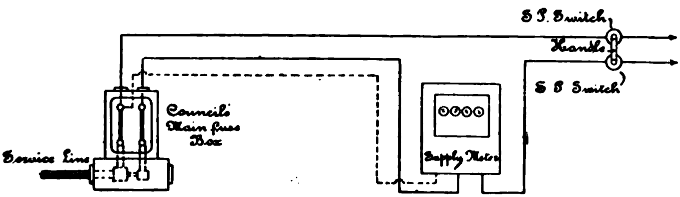


Fig. 253.—Connection of service and meters on two-wire system.

wiring contractor, and belongs to the consumer, but the undertakers usually inspect and make a test of insulation resistance, so as to ensure, as far as lies in their power, safety and reliability.

CHAPTER XII

STREET LIGHTING

Introductory.—The improvement in street illumination[1] during the past century has been considerable, although probably at no time has the *distribution* of light (if light it could be called) been as perfect as in the days when each individual ratepayer was required to lighten the darkness by means of a tallow candle or spluttering oil lamp, fixed in a horn lantern and suspended outside his house. A thoughtful wayfarer, walking through the streets of many provincial towns, or even some of the side streets in London, where a small-burner gas lamp glows at intervals of thirty to forty yards, will not become very enthusiastic upon the subject of the advantages of modern street lighting. Indeed, it is difficult to conceive that it could in many cases be much worse.

In some of the smaller towns in the provinces it is customary to light the gas lamps only during the weeks preceding and succeeding the new moon,[2] and this, of course, quite irrespective of the state of the weather, so

[1] We do not want so much intensity of light as intensity of illumination on the surface of our streets and the pavement upon which the busy traffic of streets circulates. Illumination of this character depends not on one source only, but on many sources of light distributed in innumerable ways. See paper by Sir W. H. Preece, *Royal Society*, 1884.

[2] Some provincial towns only light their arc lamps on market nights.

that, should it be stormy during a week before and after the full moon, total darkness in the streets is the result.[1] The old horn lantern and dip would be welcomed at such times. Without doubt, however, the main thoroughfares in all the larger towns and cities are now well lighted, and that the standard of illumination[2] has greatly increased since the introduction of electric lighting cannot be disputed.

Light and Illumination.—The word light, used precisely, means the luminous radiation emitted from a flame or incandescent surface, or reflected from a surface.[3] It is measured as an intensity in any direction as candle-power, the numeric of the candle-power being a measure of the rate of expenditure of energy. Light is measured as a quantity by the product of the solid angle into the mean candle-power, the total quantity of light emitted by a luminous point in all directions being 4π times the mean candle-power. When light falls upon a surface, that surface is said to be illuminated. Some of the light may be absorbed, and some may be reflected. The term luminosity[4] is sometimes applied to the brightness of an illuminated surface. The unit of illumination is the candle-foot —that is, the illumination produced by one standard English candle at a distance of 1 ft.

In connection with street lighting two graphical representations are useful:—The curve of illumination, in

[1] This is the common practice in the United States, Moonlight Schedules being published as a guide to the lighting engineer. Towns in the north of Scotland also shut off street lighting for the middle six weeks in summer.

[2] Illumination depends simply upon the quantity of light falling upon a given surface, and has nothing to do with the nature of that surface.

[3] Trotter on "Illumination," *Proc. Inst. E. E.* vol. cx. p. 70, 1892.

[4] This expression was suggested by Captain Abney.

which illumination is plotted vertically and distances horizontally; and a plan on which contour lines of equal illumination are shown. Another curve may be obtained, which has been termed the 'characteristic curve of illumination,' in which the ordinates show the illumination, and the abscissæ the areas illuminated to each magnitude in candle-foot units. What M. Wybauw calls the 'illumination effect' is dependent upon the character of the surface illuminated, and it is this quality which is sought in good street lighting, being most appreciated by the public.

Street lighting may be classed as beacon, decorative, or illuminative, depending upon the character of the thoroughfare and the object sought in placing lamps therein. The lighting of roadways by lamps of small intensity at such distances apart that the areas appreciably illuminated round the columns do not meet one another merely indicates the direction of the roadway and positions of corners and crossings; the successive lighted areas furnish timid pedestrians with oases of comfort and comparative security from molestation.[1] What is meant by decorative lighting is evident from its description; illuminative lighting, on the other hand, being the result of a serious attempt to throw a general, diffused, and ample light over the entire area of the roadway, by which illumination objects can be distinguished without difficulty.[2]

The illumination can be measured in candle-foot units

[1] Webber's *Lighting*, p. 47.

[2] It has been aptly remarked that the study of open-air lighting upon the basis of *quantity* was an outcome of the introduction of electric lighting. Webber's *Lighting*, p. 48; Boulnois' *Municipal Engineer's Handbook* (1883), pp. 140, 148.

by a Preece-Trotter illuminometer,[1] and by taking a number of measurements contour curves can be plotted. From the illumination, knowing the vertical and slant distances between the source of light and the instrument, the candle-power may be calculated. By this means the actual, and not the nominal, value of the light-giving sources may be specified.[2]

Benefits of Public Lighting.—Municipal and local authorities are entrusted with the lighting of the highways, streets, and other places through which traffic wends its way, and to which the public have access.[3] While it has been demonstrated in the law courts that the amount and class of lighting is a matter to be settled by the street authority to the best of its ability, without reference to any one else, there is an increasing and widespread demand for more general and improved lighting of places of public resort and highways.

The increased cost has to be set against a reduction in criminal offences, which diminish in number and severity as illumination is bettered; the assistance given to the keeping of law and order; and greater safety in the conduct of traffic. The tradesman and shopkeeper receive direct benefit by the increased business done and improved appearance of the streets, which tend to lengthen the hours of heavy demand, and may in electrical language be regarded as improvement in their load factor.

[1] This instrument may be used by any one without any difficulty. The writers have had considerable experience with it in practice, and have found it very satisfactory as a means of verifying statements as to street lighting.

[2] Preece, *Royal Society*, June 21st, 1883; Trotter, *Proc. Inst. C. E.* No. 110, 1892; Preece and Trotter, *Sec. G. Brit. Assn.* Ipswich, 1895.

[3] *Public Health Act*, 1875, Section 161. (38 & 39 Vict. c. 55.)

The public, therefore, whether wayfarers or frontagers, certainly get good value for the money spent in this way.

On the other hand, the central-station engineer may find his load factor increased, and the all-night lighting and lengthened demand should tend to flatten his load curve. It is also indubitably proved that good street lighting encourages custom from private consumers, and acts as an admirable advertisement for the supply. Where the municipality are undertakers, the money returns to the treasury of the local authority, and the profit which would otherwise be looked for by a trading company is saved to the ratepayers. The actual expense incurred in street lighting, exclusive of the cost of carbons, wages of trimmers, and repairs and maintenance, is the cost of additional fuel, oil, &c., consequent upon the increased load, plus the extra interest and sinking fund charges upon machinery and mains. The cost of the lamps and columns are now usually debited to the general rate in case of municipal supply.

It is in many respects desirable that the public lighting should be started at the time of commencing the supply to private consumers, as the benefit to the undertaking from an advertising and load-factor point of view is then most felt. The cost of laying special cables for the street lighting can then be considerably reduced, compared with what would be spent to lay them separately at a later period, as, if put in at the same time as feeders and distributors, the items for trenching and reinstatement are saved, and the public user of the footways is not prejudiced by having to occupy the ground a second time.

Arc Lamps.—For the lighting of large open spaces and main thoroughfares arc lamps are naturally very much in favour, and are generally adopted. The problems

which arise are electrical and optical; the first including the different means that are feasible in connection with the generation of current at the station and distribution to the lamps, the selection of that most adapted to any case, the provision for turning on and off, trimming and the like; the latter relating to the efficiency of the light sources, the positions of the lamps in the street and height above ground, the type of globe or lantern, and other considerations of a similar character.

In addition to these, which can best be dealt with in a treatise of a general character, there are local and æsthetic requirements governing the style of columns, how they are secured—by base or foot plates, the means by which the lamp is carried—simple or highly ornamental, the hours during which powerful or good lighting is considered necessary, and the cost of running as affected by current rates paid for labour, price of fuel, and such matters as bear upon the running charges.

Systems of Supply.—The light sources for street lighting by electricity are either arc or incandescent lamps, or both combined, and may be supplied either (*a*) in like manner to private customers, or (*b*) from entirely separate mains and generating plant, or (*c*) from the same generating plant, but by separate mains.

Private supply being now confined to systems operating at constant pressure, series or constant-current running requires either separate plant, or some means of regulation, automatic or manual, to maintain an approximately constant current on a circuit or circuits taken from bus bars. Again, as series circuits involve comparatively high pressures on their terminals to secure efficiency, it is obvious that a series of many lamps cannot be run off the bus bars on a low-pressure supply. Lastly, arc lamps

for alternating current working must be designed to suit the frequency on the circuit of which they form a part, and the carbons must be selected of a different size and composition to those used with continuous current. Between continuous and alternating currents comes unidirectional current, which, although possessing the distinctive character of continuous current as regards magnetic effects, varies in magnitude from moment to moment, and produces all the effects that are attributable to a periodically varying current; these being, however, inferior in intensity to those occasioned by alternating currents owing to the non-reversal of sign.

Separate Plant.—Arc-lighting dynamos were among the first machines turned out commercially, and in the early days of electric lighting the public were acquainted only with arc lamps. When the incandescent lamp was sufficiently improved to be made in quantities dynamos for so many "glow lights" were made and took their place by the side of the older arc-lighters.

The disadvantages of separate plant are:

(*a*) Increased capital cost for engines, dynamos, switch-gear, buildings, &c.:—

Firstly, per kilowatt installed, because a number of small machines cost more than one large one.

Secondly, per kilowatt useful load, because a stand-by or reserve machine must be provided *both* on arc and incandescent plants.

(*b*) Increased running cost for repairs, lubrication, &c.

(*c*) Probable increased cost of attendance.

(*d*) Low efficiency of small and of constant-current machines.

(*e*) Reduction of the load factor on the main plant during the small hours compared with what it would be if the total load were on one unit of plant instead of two; consequent increase in cost of production per unit generated.

The advantages are now generally admitted to be small, if not even *nil*, as equally good lighting can be

obtained either direct from the bus bars of the station or by the intervention of special apparatus where the alternating system is in vogue.

Motor-generators.—Motor-generators taking supply from station bus bars and delivering to street-lighting circuits may be used, the motor displacing a separate steam-engine, to get rid of disadvantage (*e*), although the others mentioned would hardly be affected. Low efficiency (*d*) of the combination is the principal deterrent in this case. It has often been suggested that continuous-current series arcs could be most readily supplied by an alternating station through the intervention of alternating-motor-series-dynamo motor-generator, but this method has not been seriously attempted in practice.

Low-pressure Continuous.—Where the general system of supply is low-pressure continuous current one of three arrangements is usually provided:

(*a*) Separate plant. This has already been considered.

(*b*) Motor-generators. In this case the primary or motor is supplied from the bus bars, the secondary or generator being wound to take the required number of lamps in series.

(*c*) Lamps in series across the distributing mains.[1] This has been adopted in many cases and is somewhat analogous to the same arrangement on alternating distributors, except that in the latter case a greater number of lamps can be run in series with a given pressure across the distributors than is possible with a continuous-current

[1] The principal disadvantage of most arrangements employing low-tension distribution for street lighting is that the lamps cannot be directly controlled from the works, therefore an attendant is required to light up and extinguish them. This, however, can be avoided by running back one of the leads to the station, as is done at Hackney.

system, where two lamps are usually connected across 100 to 110 volts and four across 230-volt mains, although in some places the number has been increased to five.

(*d*) Lamps in series on bus bars. Nine lamps can be run in series on 440 to 500 volts, and such a series may be taken off the bus bars at the station by separate mains, thus centralizing control of the lamps nearest the station, the rest being similarly switched at one or more sub-stations or switching points.

High-pressure Continuous.—The high-pressure station bus bars in a converted continuous-current system make it an easy matter to effectively deal with the street-lighting question. The available methods are:

(*a*) Separate plant. (*b*) Motor-generators. (*c*) Lamps in series across distributing mains. Nothing is to be gained by (*a*) or (*b*). (*c*) is useful where a few isolated lamps have to be dealt with; otherwise it offers no special advantages. (*d*) Lamps in series on bus bars.

With the customary pressures of 1,000 volts and 2,000 volts all the conditions are met. Thus nineteen or twenty lamps can be run in series on separate mains from the 1000-volt bus bars and thirty to forty on 2,000 volts. Any special lamps may be run two in series across the distributors at 100, or four in series on 200 volts, and so on proportionally.[1] The only objection to this method is the liability of creating faults to earth on the arc circuit and thereby stressing the rotary converters on one pole and one side of h.t. winding.

Street Lighting on Alternating Systems.—Where the general supply is by alternating current it is optional whether separate plant for the arc lighting be provided

[1] E.g. Oxford, Shoreditch.

or arrangements be made to utilize the alternators, making the generating plant common to both services.

Since the days of the old Jablochkoff candle alternating current arc lamps have been considered to be unsuitable for street lighting, not only on account of the unpleasant colour of the arc, but also of the published reports of the researches of Prof. Fleming and others, which showed that, for a given expenditure of energy, the alternating-current arc is less efficient than the continuous-current arc. In most examples of street lighting, however, intermediary apparatus is required between the source of supply and the arc, and the relative efficiency of different methods then largely depends upon the efficiency of such apparatus.

The methods adopted therefore are divisible into two classes:

Continuous Current.	*Alternating Current.*
(*a*) Separate plant.	(*d*) Lamps in series on constant-current circuit.
(*b*) Motor-generators.	(*e*) Lamps on l.t. distributors.
(*c*) Rectifiers.	(*f*) Methods involving use of alternating transformers.

(*a*) is frequently adopted, particularly in the older stations. Its objections have already been given. (*b*) has often been suggested, but has yet to be shown desirable in practice. The low efficiency is against it, and what is desired can be readily attained in simpler fashion. We shall take (*c*) next, as coming in between continuous and alternating, and then proceed to deal with the employment of alternating lamps, and the different ways in which they may be supplied.

Rectifiers.—Numerous suggestions have been made from time to time as to means by which alternating

currents could be rectified, so that the current, after passing through the proposed apparatus, became uni-

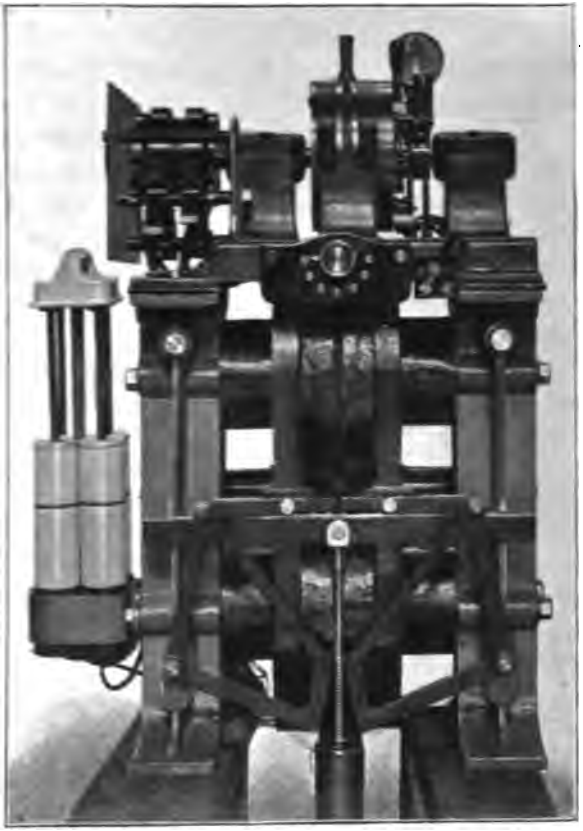


Fig. 254.

directional, the periodic variations in magnitude being unaffected, but all the waves having the same sign.

Lane Fox many years ago indicated how this could be done, through the agency of a vibrating commutator;[1]

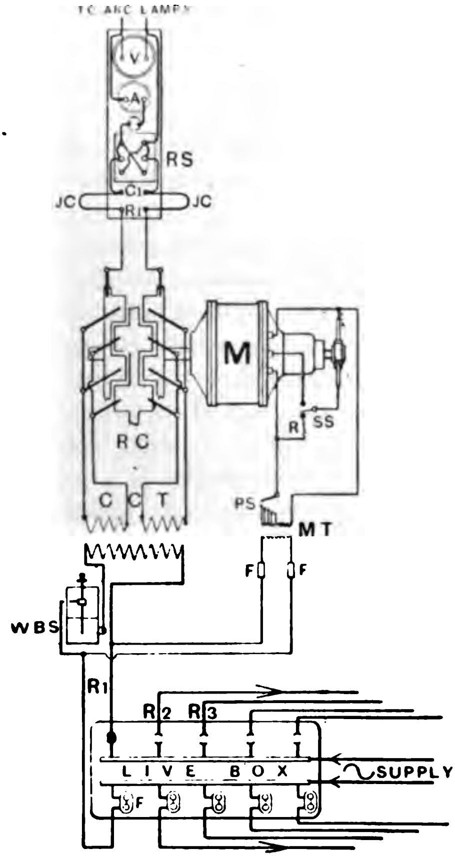


Fig. 255.

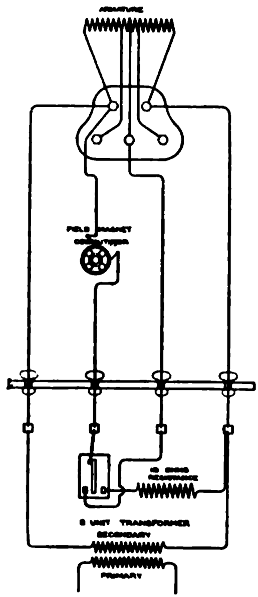


Fig. 256.

several engineers have devised means by which the waves

[1] Since reproduced in the Batten rectifier for small currents.

were caused to select paths, one for those of positive sign, and another for those of negative sign, the predetermining factor being either electrolytic cells,[1] or coils in which induced pressures were set up of a known direction relatively to the current waves to be operated upon,[2] Hutin and Leblanc, Pollak,[3] and others having worked in this field. Pollak, Rankin Kennedy, and Ferranti[4] have since devised mechanical commutating rectifiers, and the apparatus of the last-named has come into extensive use in this country.

The Ferranti rectifier consists of five parts: (1) a water-break, primary or high-tension switch, (2) a constant-current converter, (3) a constant-potential converter, (4) a synchronous alternating-current motor, (5) a segmental commutator and collector or slip rings. The combination forms a transforming, regulating, and commutating device, which is supplied at constant potential with alternating current, and whose output is a constant current of a unidirectional pulsatory or periodically varying character. The general appearance of the complete apparatus is shown in fig. 254, which gives a perspective view. Fig. 255 is a diagrammatic sketch showing the path of the current from the distributing board or "live box" through the apparatus to the arc circuit, and fig. 256 indicates the connections of the motor. The h.t. switch (W.B.S.) consists of porcelain tubes partly filled with water, a porcelain lid being placed over the tank.

[1] *Elect. Review*, vol. 41, pp. 2, 495, and 613, 1897; *Wied. Ann.* vol. 62, p. 323.

[2] Tesla.

[3] "A Novel Method of Transforming Alternating into Continuous Currents," *Proc. Inter. Elec. Con.* (Chicago, 1893), p. 438.

[4] Patent, No. 17,220, October 9th, 1891.

The objects attained are two-fold—the load on the bus bars is put on gradually, and the effects of electro-magnetic inertia or inductance in the uni-directional arc circuit are minimized. Quick-breaking would lead to excessive pressures being set up in the arc circuit, with a tendency to cable break-downs.

The constant-current converter (C.C.T.) comprises four primary coils, in two sets, coupled in series, and hung from horizontal knife-edge bearers. The secondary coils are fixed on the upper and lower horizontal members of a rectangular set of stampings, forming the magnetic circuit. The two sets of primary coils are movable, and in action mutual repulsion between the primary and secondary windings causes the former to be repelled outwards and away from the latter: this action is balanced by weights. The regulation is remarkably good: with the weights set for 12 ampères on a 30-lighter with two-thirds load the current only falls to 11 ampères on full load, and merely rises to 14 ampères on short circuit. The primary current is, however, large for the watt input, the power factor being as low as 0·6 at full load, and the current is but slightly affected by changes in secondary load, the lag increasing as load is taken off.

The constant-potential converter (M.T.) is of the usual pattern, its only peculiarity being the addition of tappings on the secondary side, connected to multiple point switches (P.S.), which allow of the current being taken off at anything between 60 and 100 volts by steps of two volts. This provision enables the motor to be supplied at whatever pressure gives the most steady running, and to be speeded up to synchronism rapidly at full pressure.

The motor, M, has a tunnel-wound-stator, or armature, and four-polar rotor, or field magnet. The field winding

has its ends brought to a two-part commutator with four peripheral segments. For starting the field is connected through a 10-ohm resistance coil across the 100-volt transformer secondary, in parallel with the armature. When synchronism is attained, and the motor-stator has been brought forward about 90° from its initial position, by means of a two-way switch, S S, the field winding is placed across part of the armature winding. The field is then excited by a uni-directional current.[1] Tappings, T_1, T_2, T_3, from the armature winding are provided, to enable the best value of excitation to be taken, by changing from one to the other as may be desirable. The commutator and brushes, R C, resemble in many respects those found on a Thomson-Houston arc lighter.

It is claimed for this apparatus that by its use—

(*a*) Separate plant is rendered unnecessary and the capital cost of the installation is kept low, the floor space occupied being small.

(*b*) The current is supplied to the rectifiers direct from the station bus bars, thus effecting considerable economy by loading the engines, which would otherwise be running under light load during the small hours of the morning.

(*c*) A pulsating current is supplied to the lamps, which improves the regulation of the feed mechanism by keeping it in a state of vibration, and thus preventing sticking of the rods and other parts, and the regulation for constant current is good.

(*d*) A better light is obtained for a given expenditure of energy with a rectified current than with an ordinary direct continuous current.

(*e*) The expenditure on repairs and maintenance is small compared with separate plant.

(*f*) The efficiency of the apparatus being high, economy in supply to the arc lamps is secured.

At the convention of the Municipal Electrical Association held at Manchester in June, 1897, three papers

[1] Consult S. P. Thompson, *Polyphase Electric Currents.*

were read on the subject of street lighting, the discussion upon which was confined chiefly to rectifiers.

Alternating Arc Lighting.—Recently the alternating-current arc lamp has again come to the front, and several successful installations of street lighting on this system are now in operation. While it is acknowledged that the physical laws governing the arc itself militate against a high light-giving efficiency *at the arc*, there are so many losses between the generators and lamps, the transformation or rectification, and separate plant, &c., has such a low efficiency, that some engineers consider it to be true economy to simplify the system by eliminating all the intermediate parts, and using alternating-current arc lamps of a higher power and larger current. For the same total watts taken from the bus bars the same number of lamps can be supplied, with a resulting total illumination and effect as good as any combination of rectifiers or separate appliances,[1] and a better distribution of light, since the rays are thrown rather further out. Where the general system of supply is an alternating-current one, there are many obvious advantages in using the same system for the street lighting, provided it is reasonably efficient.

The most important are—

(*a*) Simplicity—one type of plant only required.

(*b*) No intermediate moving plant, and therefore less risk of extinction and less supervision required.

(*c*) Good plant load factor.

A. *Alternating Series Lamps.*—The lamps may be run in series circuits from the bus bars through a regulating

[1] In the case of separate plant comparing steam consumption with steam consumption.

or constant-current transformer or choking coil, which is required in order to obtain a constant current.

Comparatively little has been done in England towards running a number of alternating lamps in series, and therefore any definite expression of opinion on the subject generally would be premature, although the system is in successful operation.[1] Should continued experience prove the reliability of the system, it will, no doubt, be largely adopted. As will be seen, it possesses all the advantages claimed for the other methods, with the exception that the lamps are not independent of each other, and, as is the

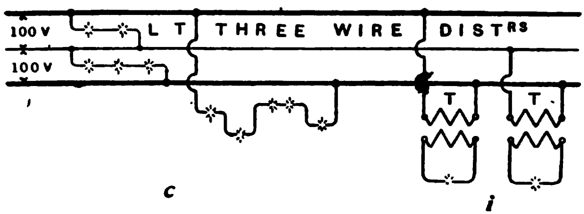


Fig. 257.

case with all series circuits, the risk of breaking down the insulation of the lamps is very much greater. This can be obviated by running the lamps on the secondaries of constant-current one-to-one ratio transformers, a method devised by the Westinghouse Company and extensively used for some years. Compensators, or choking coils, placed in parallel with arc lamps, form a ready means of keeping the circuit closed in the event of the carbons "hanging," or a failure of the "cut-in" device to do its duty by short-circuiting the lamp.

B. *Alternating Distributors.*—The lamps can be con-

[1] E.g. Worcester, Islington.

nected in series of two or three across the low-tension 100-volt, or five or six on the 200-volt distributors (*c*, fig. 257). Choking coils are usually necessary in this case, to prevent over-feeding, and generally to steady the current. Single lamps may be run off the secondary coil of a transformer, T, whose primary is across the distributors (*i*, fig. 257). This is less wasteful than the use of large chokers, renders the lamps independent of each other, and reduces the idle current taken from the low-pressure mains. Thus transformers 100 volts to 37 volts and 200 volts to 37 volts are used in many cases with satisfactory results.

C. *Alternating Transformed.*—These methods are capable

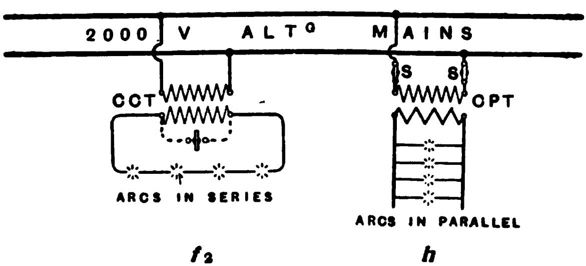


Fig. 258.

of being used either on the ordinary high-tension feeders or on special mains run for street-lighting service only.

(1) A circuit of lamps may be connected in series across the terminals of a suitable transformer, a number of which can be distributed over the district to be lighted (f_2, fig. 258). (2) A number of lamps may be put in parallel and fed by a suitable transformer (*h*, fig. 258).

The two foregoing methods are seldom used with

separate arc mains, being usually confined to street-lighting taken off the high-tension feeders, when the switching is arranged for on the primary connections to the transformer.

(3) Each lamp supplied from the secondary of a separate transformer, the primary of which is fed by a special main (*g*, fig. 259).

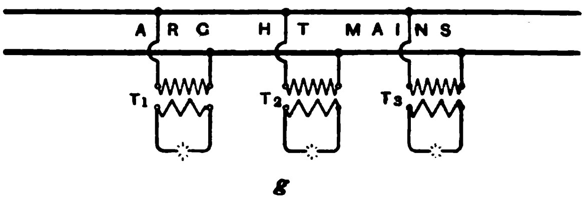


Fig. 259.

In this case the transformers are placed either in the foot-way or in the pedestals of the lamps. The arrangement of transformers may be such as indicated in figs. 260 and 261 or 262 and 263. The pressure is transformed down to about 37 volts, and connected to the lamp direct through a pair of fuses. Sometimes, however, a somewhat higher pressure is adopted and a choking coil is introduced.

Engineers who favour this system claim—

(1) That it is economical, inasmuch as the transformers are always working at their highest point of efficiency, and are out of circuit at other times.

(2) That circuits of 30 to 50 lamps require mains no heavier than is required for a similar number of lamps supplied by a series system.

(3) That all the lamps can be controlled direct from the works.

(4) That the supply being taken direct from the bus bars, no intermediate moving apparatus is necessary, thus avoiding the risk attendant upon the use of rectifiers.

(5) That each lamp in the circuit is independent of all the others.

(6) That as the losses in rectifiers or small plant, and the cost of the necessary repairs and attendance consequent upon their use, are saved, they can afford to supply a heavier current to the lamps, and obtain an illumination equal to that of continuous-current lamps at the same cost.

(7) That the risk to the insulation of the lamps is much less than in a series system.

The Arc as a Light Centre.—The effectiveness of arc lamps for street-lighting purposes varies very considerably, and depends upon a number of conditions, amongst the most important of which are the following:—

(1) The height of the lamp above the street.

(2) The position of the lamp in the street.

(3) Whether globes or lanterns are used.

(4) The shape of the lanterns or globes.

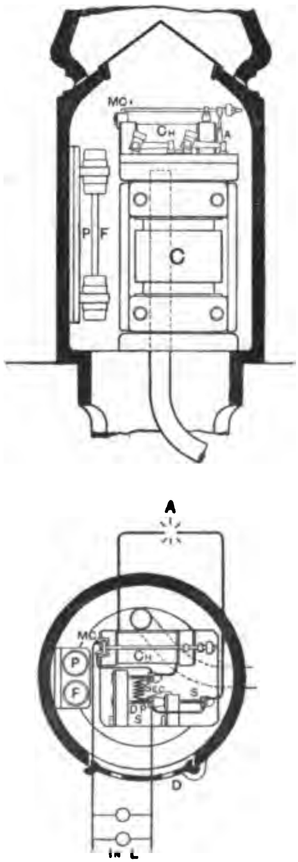
(5) Quality and density of the glass.

(6) Quality and size of the carbons.

(7) Whether the lamps are focussing or non-focussing.

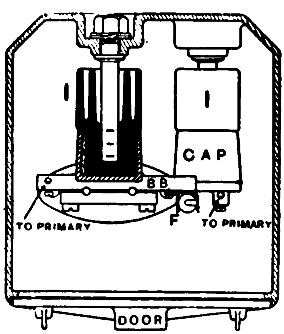
(8) Length of the arc, and power expended in it.

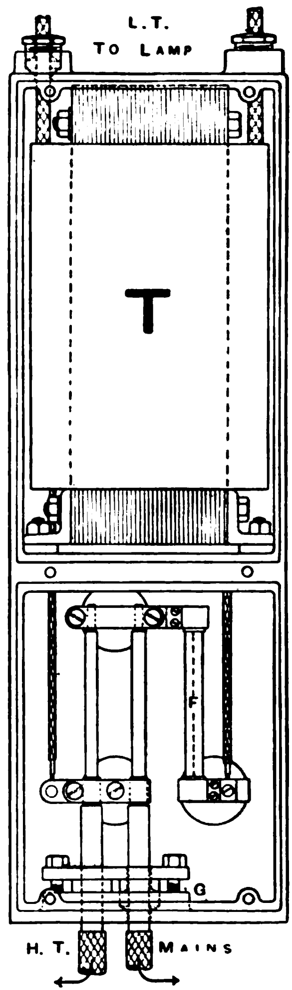
(1) The height of the column usually depends upon whether it is fixed in the foot-



Figs. 260 and 261.

way or in the middle of the carriage-way; in the former case from 18 to 20 ft. to the arc is the height usually adopted, while in the latter case much higher columns are generally used, and from 23 to 25 ft. is not uncommon.[1] Where the lamps are at considerable distances apart, intermediate columns of from 20 to 23 ft. high are preferred, even in the former case. Short columns tend to patchiness and bad distribution, but are useful in the case of lamps fixed close to bridges spanning the road lighted. Groups of lamps on high towers were at one time the vogue in America,





Figs. 262 and 263.

[1] Minimum of 10 ft. is prescribed (*Board of Trade Regulations*, No. 45).

but the results did not justify further extensions on such lines.

(2) There is no doubt that where it is possible to fix the lamps in the centre of the carriage-way by far the best effect is produced, there being a better diffusion of light and less absorption than when they are fixed on the foot-way. Unfortunately, streets are frequently too narrow to admit of this arrangement, or where the traffic is very heavy considerable obstruction is the result, while in some parts of London and other cities the streets are already occupied by the tramway companies' lines, and there is generally insufficient space between the two lines of metals to allow of lamp columns being erected, and the moving of the rails would be a very costly matter. It is for these reasons that the lamps are so frequently erected on the foot-ways.

Objections are sometimes raised to the obstruction in the foot-way or road-way caused by lamp columns. This has been met to a limited extent by the use of brackets or by suspending the lamps over the centre of the street from cross wires secured to buildings on either side. This is open to the following criticisms: (*a*) permission from owners and tenants has to be obtained, (*b*) obstacles are placed in the way of fire escapes, &c., (*c*) the lamps are difficult to get at for trimming, and (*d*) the appearance of the suspenders is not artistic. In one or two cases light iron arches have been sprung between abutments, and the lamps hung from the centre.

Where lamps are fixed over the foot-way it is customary to select the positions at the intersection of main and cross streets, so that the side street gets some benefit, and the junction where the traffic is likely to be dense is well illuminated.

The distance between adjacent lamps is generally about 60 yards: different localities show figures from 45 to 300 yards. Where the centre of the road-way is chosen the distance may be from 70 to 100 yards; lamps on the foot-way are often placed from 100 to 130 yards apart on each side, those on the one side being set half way between those on the other.

(3) Comparatively few lanterns are used for street-lighting purposes, and in London they are only in use in the City.[1] Their chief advantage lies in the fact that if they are accidentally broken they can be easily repaired: people who favour globes object to lanterns on account of the obstruction to the light caused by the framework. Globes do not possess this disadvantage, but they are easily broken and cannot be repaired.[2] Lanterns are generally regarded as having a better appearance than globes.

(4) There is very little variety in the shape of lanterns used for electric lighting in streets. The plan is usually that of a hexagon or octagon. Spherical globes (fig. 265) appear to be mostly in favour. Where oval or elliptical globes (fig. 264) are adopted an unpleasant shadow, both at the top and the bottom of the globe, is the result. This is not present when spherical globes are used.

(5) Lanterns are usually glazed with rippled[3] or some form of roughened glass, and in London considerable

[1] Hastings front is a good example of lantern fittings.

[2] Lamps must be guarded, to prevent ignited carbon or broken glass falling from them (*Board of Trade Regulations*, A, No. 44).

[3] Mr. Preece and Lieut.-Col. Haywood tested different kinds of glass before deciding on the City of London lanterns, and found respectively—

	Thickness, inch.	Per cent. loss by absorption.
Ground glass	0·058	46·24
Opal ,, ...	0·072	25·18
Rippled ,, ...	0·145	21·73

difficulty has been found in keeping this glass clean, and it will be readily seen that if dirt lodges in the roughness

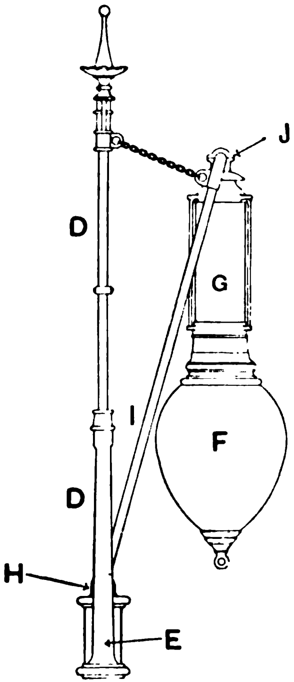


Fig. 264.

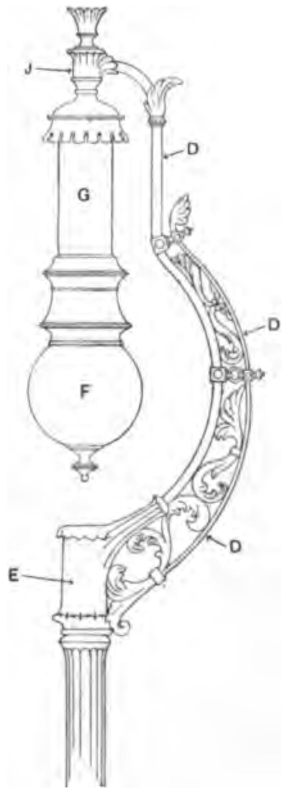


Fig. 265.

D, fixed crutch; E, casting fitting on column top; F, globe; G, cylinder covering mechanism; H, hinge; I, swinging inner crutch; J, swivel piece carrying lamp (below this is a porcelain insulator isolating lamp frame from earth).

of the glass, considerable diminution of the light will result. The quality and density of the glass of course

materially affect the light. Clear glass globes often cut off 10 or 15 per cent. of the light; and obscured glass, such as is generally used for arc lamp globes, may reduce the light 50 or 60 per cent.[1] It is claimed for dioptric, muranese, holoplane, and other specially designed forms, that the light is distributed uniformly, and that a better result can be obtained, as the upward rays are refracted, and reflected downwards. The most common material for globes is, however, opal or opaline glass.

(6) The quality of the carbons varies considerably, and affects both the colour and intensity of the light, and unless they are homogeneous throughout it is quite impossible to keep the arc steady. In the case of alternating arc lamps the quality of the carbons is of vital importance, and too much care cannot be taken in their selection if a good light is desired. Carbons are also sometimes bent, with the result that they may be perfectly centred when the lamp is trimmed, but as they burn away they get out of centre, and an unpleasant shadow on one side of the globe or flickering of the arc is the result.

Many attempts have been made to increase the light given by the arc by introducing gases and oils into it. Thus Saunderson[2] passed a hydrocarbon oil into the negative carbon by a wick. Special flame carbons can be obtained which bid fair to eventually give good results.

Considerable improvement in the colour of the light

[1] The writers have tested the effective candle-power of a 600-watt rectified arc lamp in the street with opaline globe on and off—with globe on = 500 c.-p., with globe off = 1,100 c.-p. in round figures. The loss, however, was less than the figures indicate, owing to the difference in distribution and a slight gain in some directions by reflection from the globe.

[2] *Elect. Eng.* p. 386, May 16th, 1890.

as well as a much higher efficiency has been obtained, however, by the use of a mixture of carbon and other mineral matter.[1] The colour varies from a pale warm yellow to a rich orange, and it would appear that it is peculiarly suitable for street lighting in London and other places afflicted with a foggy atmosphere, as its power of penetration is remarkable. That this form of lamp has not become more popular is due partly to the extra cost of the carbons, but mainly to the defective or unreliable character of the feeding mechanism in the lamps. Several reliable lamps of this class have recently been introduced which give good results, and their use is rapidly spreading. For this flame-type of lamp the alternating current is found very suitable.

The size of the carbons also materially affects the candle-power. Large diameters are sometimes used to increase the duration, but at some sacrifice in efficiency. Speaking generally, the size (or diameter) should be proportioned to the current, and the length to the duration desired. Single-carbon 16-hour lamps are now used largely for street-lighting. The physics of the arc has been exhaustively treated by many able writers, and engineers who have charge of street-lighting systems are referred to these authorities for information on this part of the subject.

(7) In the case of a non-focussing lamp, as the carbon burns away the arc gets nearer to the bottom of the globe or lantern, with the result that the shadow of the top of the lamp column or spark-catcher gets broader, until a large portion of the street is in comparative shadow. This, of course, does not apply if focussing

[1] Bremer and flame type of carbons.

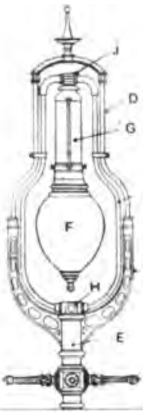
lamps are used, and there can be little doubt that they are more effective for this reason.[1]

(8) The amount of light given by a lamp depends very largely upon the length of the arc, which has to be carefully adjusted in order to obtain the best results. If the arc is too short, a bad light is obtained; while, on the other hand, if it is too long, flaming is the consequence, as well as unsteadiness. The best point is naturally somewhere between the two. The pressure across a continuous-current lamp is taken as from 42 to 43 volts on the arc; with alternating current this drops to 36-37 volts virtual. The usual power expended is 450 to 500 watts per lamp for 10 amp. c. or 12 amp. a., a 20-amp. alternating taking 700 watts and a 15 amp. continuous absorbing 700 watts.

Street-Lighting Circuits.—It is advisable, and has now become customary, to divide the arc lamps between two or more circuits in any street, so that in the event of a fault occurring on a main, only a portion of the lamps are extinguished, and the other circuit continues to supply light.

Where the traffic is heavy it may be a very serious matter for the street to be suddenly plunged into total darkness. Even in the event of a partial disablement of the machinery it may be possible to keep one circuit running. Sometimes the circuits are so arranged that each controls one side of a street, and sometimes each alternate lamp is on alternate circuits. The advantages of either arrangement from an economical point of view are also considerable. At midnight, or at some other suitable hour, half the lamps can be extinguished, thus reducing the

[1] The construction of arc lamps and mechanism employed has been fully dealt with in Maier's volume in this series.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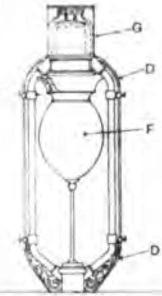
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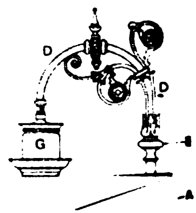
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light and consequently the cost. Instead of having half the arc lamps burning throughout the night, each lamp column is sometimes arranged to carry one or more small incandescent lamps in arms projecting from the column (fig. 267). At midnight the arc lamps are turned off; the incandescent lamps are kept alight during the remainder of the night.

When the arc lamp columns are utilized for incandescent lighting after midnight, as described, it is usually found that supplementary lighting is necessary, as the arc columns are too far apart to allow of proper distribution with small lamps. In such a case additional columns are erected between the others, or existing gas columns are utilized.

At first sight the entire extinction of the arc lamps at midnight, and replacing them with two or more incandescent lamps, may appear to be far more economical than turning out half the arc lamps, as before described, but as a matter of fact the increase in economy is very small, while the decrease in light is considerable. If each arc lamp of, say, 500 watts each is replaced with two incandescents of 32 c.-p. each, as is usually done, the saving on a circuit of ten lamps is 100 watts only over that effected by extinguishing half the arcs. Another method is to reduce the current supplied to the arc lamps. Thus in one case the lamps are run at 12 ampères until midnight; afterwards the current is kept at 6 ampères. Special care must be taken in selecting lamps to see that they will not hang or overfeed at either of the current magnitudes employed.

As a rule, lamps are placed 30 on a circuit in urban lighting to 50 on a suburban circuit. In America 100 lamps are often run in one series. Where parallel series

connecting is in use smaller circuits, such as 12 to 20 lamps on each, are customary. Where the street-lighting is taken from the distributors there is little risk of extinction, owing to the supply coming through several feeders.

Enclosed Arcs.—By enclosing the arc in an air-tight glass cylinder the duration of the carbons is increased; less frequent trimming is required; the mechanism of the lamp can be simplified, as the feeding is very much slower; and a higher pressure can be used across the arc, as it can be lengthened without flaring.[1] Thus lamps can be made to take half the current and double the pressure of open forms. With alternating currents more difficulty is found in devising an enclosed lamp than with continuous, but at least one type is in experimental use. Enclosed lamps will in time be likely to come more largely into use for this purpose.

Mercury Vapour Lamps.[2]—A comparatively new type of lamp which in principle differs materially from both the arc and incandescent types is that known as the mercury vapour lamp. In its present form it consists of a vacuum-tube with metallic electrodes at either end. At one end is a bulb partly filled with mercury into which one electrode passes. Upon connecting the electrodes to a sparking coil the internal resistance is reduced sufficiently to allow the current from an ordinary lighting circuit to pass, and the mercury vapour produced becomes incandescent. The light is intense, but as the spectrum is almost lacking in red and yellow rays, the light is not suited to domestic or internal lighting, as all colours are practically reduced

[1] The enclosed arc lamps which have been actually used are the Jandus, Howard, Stewart, Davy, Ajax, Solar, Lewis, &c.

[2] The Cooper Hewitt Mercury Vapour Lamp and Bastian Lamp.

to various shades of blue and green. Several improvements have been recently made, and it is probable that it will develop and become popular for many purposes. Its efficiency is stated to be much higher than the arc lamp. The inventors found that if an alternating current was used, the lamp acted as a transformer and the current became uni-directional.

Incandescent Lamps.—Many devices have been introduced with a view to running incandescent lamps on the same circuits where series systems of arc lamps are in use for street lighting,[1] but they do not appear to have met with much favour. Such arrangements, moreover, can only be looked upon as make-shifts, as it is probable that even in districts where special plant is now used for street lighting, and where the arc lamps are run in series, the lighting of side streets will be conducted either direct from the low-tension mains or by means of separate transformers in the case of high tension in preference to the arrangement described. High candle-power incandescent lamps for street lighting do not as yet appear to be used to any great extent, due doubtless to the fact that they are less economical in the consumption of energy than arc lamps, and rapidly deteriorate if run for several hours nightly.

The illumination of the streets by means of small incandescent lamps would not appear to possess much, if any, advantage over gas lighting, but it must be remembered that when the local authorities are the "undertakers" the actual cost of lighting is limited to the cost of production at the works and renewals of lamps, and it is stated that where this system is used it compares very favourably

[1] Chap. V., "Series Incandescents."

with the cost of gas, while it enables the whole of the street lighting to be conducted by the local authorities.

The Nernst Lamp.—This lamp differs from the ordinary incandescent lamp in several respects. It does not require a vacuum, the filament, or "glower" as it is called, is not of carbon, and its efficiency is much higher. The "glower" consists of a thin rod made up of one of the rarer earths which has the property of becoming incandescent at a lower temperature than carbon. At the normal atmospheric temperature the resistance is very high, and it has to be artificially warmed before it will light up. A small warming coil surrounds the "glower," but as soon as the resistance of the latter falls sufficiently it lights up, and the warming coil is automatically cut out. The main difficulty with this lamp has been its short life, but considerable improvement has been made, and it may now be considered a commercial article.

In the case of low-tension supply it would seem that to the cost of electricity and renewals would have to be added the wages of attendants to turn the lamps on and off, and these in London in foggy weather would be a considerable item, and even if special mains were laid, enabling the lamps to be lit or extinguished at the works, greatly increased capital outlay would be necessary, particularly if the lighting extended over a wide area. Where the police are under the lighting authority the policemen on their rounds may turn the lamps off and on.[1]

Switches.—Series lamps must be provided with cut-off switches, which enable the lamp to be entirely disconnected from the circuit,[2] while the switch must be of a form safely operated in the dark and not likely to cause

[1] See paper by E. E. Hoadley, *Mun. Elect. Convention*, **1905**.
[2] *Board of Trade Regulations*, A, No. 46.

injurious arcing, sparking, or heating. Several forms of switch to comply with these conditions have been made. Automatic switches for (*a*) throwing in incandescent lamps when the arcs are turned off, or (*b*) lighting up side-street circuits when the main circuits are switched on, also fall in the category of street-lighting apparatus.

Lamp Columns.—The designs of lamp columns and supports are manifold, but many points have to be considered before deciding which is the most suitable for the purpose in view. The columns should be ornamental by day and useful by night; must not present obstacles which will seriously interfere with traffic, and must not be fragile or liable to be damaged by partial collision, &c. Many which are very pretty in design, as well as effective from a lighting point of view, render the trimming a matter of great difficulty, and it is not uncommon to see a very cumbersome form of telescopic ladder on a truck being trundled along the streets to enable the lamp trimmers to do their work. It is obvious that any form which renders the use of heavy ladders necessary must increase the cost of trimming.

The columns are fixed in position by a foot-piece or base, which, after being placed in the ground and levelled, is surrounded with concrete. In the lower part of the column space has to be found for switches, and with alternating lamps the converter is conveniently put out of harm's way by being enclosed in the column. In some cases this is broadened out and becomes a sub-station for the supply to consumers within a small radius. The supply cables come up from below, and connect on to the lamp leads, a door or shutter giving access to the connections. Lamp frames should be insulated from the electric circuit, and also from the crutch and column;

columns should be properly earthed, so as to prevent leakage charging the exposed ironwork to a dangerous pressure above the surrounding pavement and soil.

In trimming access has to be obtained to the lamp, and to enable the trimmer to do this the following methods are in use :—

(*a*) Long ladders reaching from the ground to the lamp crutch or bracket, usually handled by two men.

(*b*) Tower ladders mounted on trolleys, on wheels, sometimes drawn by a horse, or wheeled about by two or more men.[1] With the former the trimmer has a belt or sling, by which he secures himself to the crutch during the time he is at work. Towers have a platform at their upper extremity, from which the lamp is easily handled without material risk.

The portion of the column carrying the lamp may be made to provide a seat for the trimmer when at work, if the lamp can be swung outwards. Fig. 266 shows the side view of the column, fig. 264 with the inner crutch in the trimming position.

The overhanging bracket column (fig. 268) is probably one of the most effective for street-lighting purposes, but the objection to it lies in the fact that a special form of ladder is absolutely necessary for trimming, owing to the inaccessibility of the lamp. Even with an upright column, as shown in fig. 267, which seems to be more generally used, no provision in many cases is made for getting at the lamp, except by the use of a long ladder, which has to be carried all over the district.

Several arrangements are in use, however, for avoiding this necessity :

[1] These appear to have a short life and to be dangerous in high winds. Fedden on "Street Lighting," *Mun. Elect. Assoc.* 1897.

(*c*) Columns fitted with short pieces of iron rod with a round head at each end, passing through holes in the columns on alternate sides, forming a number of movable steps; these lie concealed, all but the heads, until wanted, when they are pulled out by the lamp trimmer as far as the head on the rod will allow, enabling him to ascend the column, and set back into position again when the work of trimming is completed.[1] This apparatus necessarily increases the cost of the column. Another somewhat similar arrangement comprises—

(*d*) Columns provided with a structure like a parallel ruler concealed and bedded in each side when shut up; when opened, a ladder with column as centre stave is formed.[2]

(*e*) A very simple form is that shown in fig. 266. Semicircular holes are left in the column when it is cast, and removable steel steps, which are carried by the trimmers, are inserted in order to ascend, these being removed while descending.[3]

(*f*) Hauling-gear introduced many years ago has not extended very rapidly, in consequence of the loose connections necessary between the lamp and the hood which became defective. Improvements, however, have been made from time to time, and it is again coming into favour. There is no doubt that, if it can be relied upon, this is the simplest form of all and the most convenient.

Roughly it consists of a stranded steel wire—attached to the lamp—which passes through the crutch or swan neck and down the column, where it is fastened to a winch

[1] Devised by the Brush Co.

[2] Suggested by the late Lieut.-Col. Haywood, engineer to the City Commissioners of Sewers.

[3] Proposed by Major-General Webber.

inside the base of the column. A ratchet and pawl and a loose handle enables the lamp to be lowered or raised, or held in position as required. Sliding electrical contacts break the current at the top of the lamp as it descends, and remakes it when hauled into position. Of course the lamp must be switched off before being lowered.

CHAPTER XIII

RUNNING AND MANAGEMENT

The Supply.—The first object of the electrical engineer of a central station should be to give a satisfactory supply to the consumer, not only because the law demands it, but also because the ultimate success of the business depends upon the demand for electrical energy, and it is evident that, unless the supply is satisfactory, the demand will be seriously curtailed. Every consumer will, if he is satisfied with the supply, induce others to do as he has done, either by directly or indirectly advertising the fact.

A satisfactory supply may be understood to mean, briefly:

(*a*) A supply which is uninterrupted, and therefore always available.

(*b*) A general maintenance of the standard pressure, as well as an absence of momentary fluctuations.

(*c*) Reasonable in price.

Taking these points as stated:

(*a*) In order to avoid interruptions of the supply, or to minimize them as far as possible, it is essential that:

(1) Reliable plant and mains be used.

(2) Sufficient reserve plant be provided.

(3) Efficient means be provided to expedite repairs.

(4) The arrangement of mains be such that in the event of a fault occurring it can be quickly localized, and as few customs as possible be affected.

(5) An efficient staff be engaged.

(6) The whole scheme be designed with the continuity of supply as the primary object in view, consistent with a reasonable capital outlay.

(*b*) The maintenance of the standard pressure can only be effected by an efficient system of mains, as well as by proper attention at the station.

(*c*) Assuming that the supply is satisfactory in other respects, the question of cost naturally arises, and it is of considerable importance both to the consumer and the undertakers. No matter how good the supply may be, if the charge is prohibitive the undertaking will be a failure financially; while, on the other hand, if the charge is a reasonable one, the demand will probably be great, and the undertaking a success, provided due economy has been observed in generation and distribution.

Costs.—So long as electricity supply was a business in which emulation was a thing comparatively unknown, electric lighting a luxury and an advertisement of a somewhat novel character, the public were prepared to pay what would now be looked upon as exorbitant prices, and the station engineer had little inducement to closely examine his costs sheet and to effect sundry small economies which would have the effect of reducing the expense of keeping up the supply. Coupled with this was the fact that in pioneering work the technical problems which were always cropping up required more than average skill to satisfactorily surmount the difficulties involved, and it was not surprising that less attention should be paid to finance and organization than to electrical engineering questions which were for the most part unprecedented, and in dealing with which there was no prior experience to form a policy, and thus enable them to be readily disposed of.

As the business developed, and supply became more general, the technical questions involved ceased to call for a lavish expenditure of time to cope with them, and station engineers and managers were able to vie with one another in reducing the cost of production, and arranging the details of the works routine in such a manner that

nothing was left to chance or done by haphazard. The result has been that there is no branch of industry in which the cost of working is better known, or machinery run at a higher ascertained efficiency, than in electricity supply.

The cost of production of any commodity will, of necessity, depend largely upon the quantity produced, for it is evident that certain charges, such as those of administration, are practically standing charges, and do not increase in the same ratio as the increase in the business. In the case of electrical energy, the cost of production depends not only upon the quantity produced, but also upon the manner in which it is demanded. In Chapter VI., under the head of "Price and Methods of Charging," this is clearly set forth, and the sale of electrical energy is there shown to be far more profitable when the demand is spread over a long period per day than when it is confined to a short period, although the amount produced may be precisely the same in both cases. The class of demand in any district will depend upon the class of consumer, his business, domestic habits, and other considerations.

Character of Load.—Fig. 269 represents a characteristic

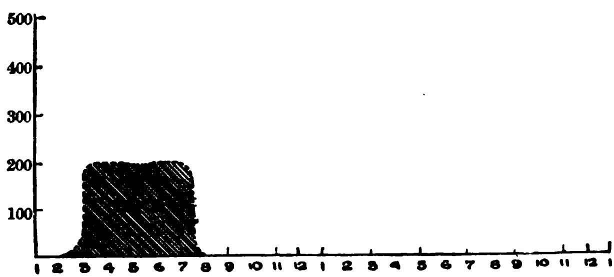

Fig. 269.

load curve on a dull day in November in London, where the demand is entirely confined to shops which close at 7.30 p.m., and where the lamps are not required during the hours of daylight. It will be seen that the whole of the electrical energy demanded is consumed in 4½ hours from 3 to 7.30 p.m., while the same plant would be capable of maintaining the supply for the whole twenty-four hours if demanded.

But for the provision in the Order requiring continnous running, the station could be shut down for nineteen and a half hours out of twenty-four, and during the summer months the demand would practically cease altogether.

Fig. 270 shows the effect produced by the addition of a number of private houses, the slight rise between 6 and 10 a.m. being due to servants lighting up while cleaning the house, and also during the breakfast period.

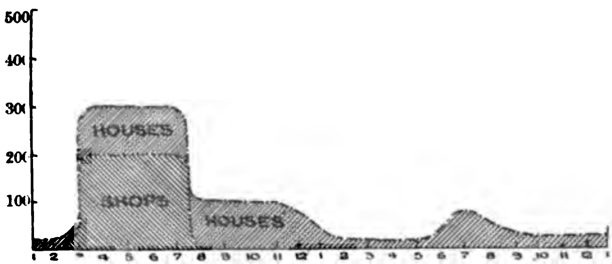

Fig. 270.

It will be noticed that there is a small load during the day, as in nearly every dwelling-house, particularly in the basements of London houses, some lamps are in use all day long.

In this figure, although the number of hours during which there is a demand has increased, the peak of the load for shop-lighting between 3 and 7.30 p.m. has

increased by that required for the private houses, thus requiring additional plant, and the original machinery is idle just as long as before.

Fig. 271 shows the result when the demand includes threatres and places of amusement which open at, say, 7.30 p.m. Here it will be found that at about the time the shop load goes off the theatres come on, and the load is continued right up to midnight, thus extending a portion of the load to that period, *without additional machinery.* In this case a fairly good load is maintained

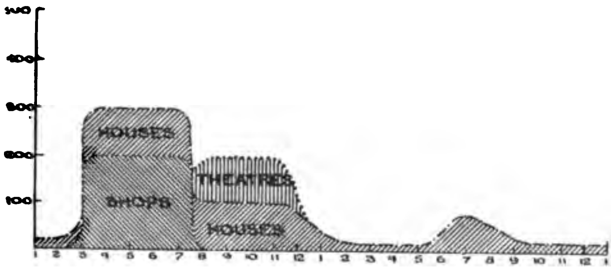

Fig. 271.

for nine hours, but still there is very little demand during the remaining fifteen hours per day.

It is obvious that if the energy consumed during the nine hours could be spread over eighteen hours, the same revenue would result (provided the price was a fixed one) with only half the machinery running, and the capital expenditure required on plant would therefore be only half as great.

Public street lighting is always desired by the central station engineer, for, although it increases the peak during the heaviest part of the load, it also loads up machinery when it would otherwise be running practically empty for several hours during the early morning, and the load is

steady and reliable, as well as an excellent advertisement if good. Fig 272 shows the effect of adding the street-lighting load to the previous diagrams.

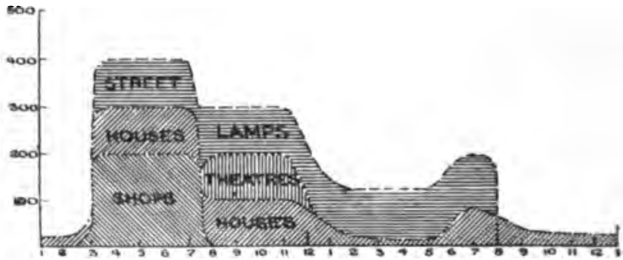

Fig. 272.

Fig. 273 shows the actual load curve of a station in London from which very few private houses are supplied. As will be seen, the period includes four days during October, and the load commences later than given in the previous diagrams. The Sunday curve shows the effect

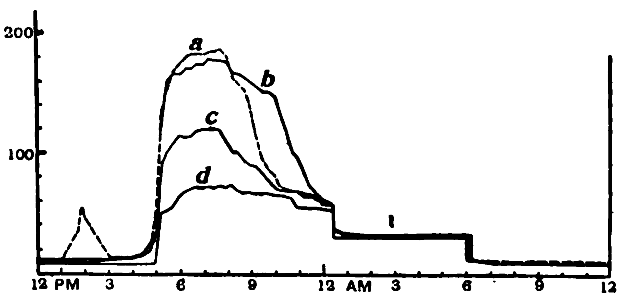

Fig. 273.

a, Tuesday, October 19; *b*, Saturday, October 23; *c*, Thursday, October 20; *d*, Sunday, October 17.

of closing the shops and places of amusement. Half the street lamps are extinguished at 12.30, and the remainder shortly after 6 a.m. The small rise between 1 and 3 p.m.

is due to local fog during that period on the Tuesday, while the increase in the hours of lighting on the Saturday is caused by the shops which close later on that day.

Generally, the daytime is the period when the demand is at its lowest, as well as the commercial efficiency of the station, the cost being usually out of all proportion to the revenue.[1] Fig. 274 shows the very great difference between the demand on the lightest and heaviest outputs

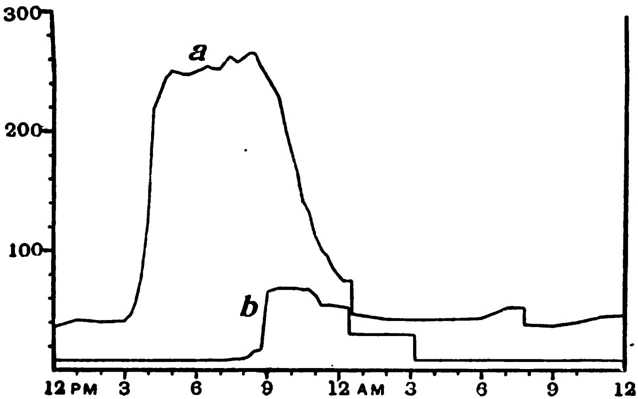

Fig. 274.

a, Thursday, December 23; *b*, Sunday, July 11.

in a year. The load curves on a summer Sunday and on one of the days immediately preceding Christmas indicate the difficulty which besets any one who proposes to fill up the valleys and run machinery all the year round at an economical load.

With a view to encouraging a demand during the

[1] In a paper by Mr. Arthur Wright, read before the Municipal Electrical Association, 1896, the whole subject of works costs is ably dealt with.

daytime, numerous suggestions have been made, and it is usual to charge a lower rate per unit for a day supply than at other times, for it is obvious that the costs of administration, &c., will be the same as long as the machinery is running, whether it is loaded or not, and the only additional cost entailed in the former case is due to the increase in consumption of coal, water, oil, waste and sundries, &c. A demand for electrical energy for motive power, cooking, heating, welding, &c., has been pointed out as a suitable means of maintaining a day load (and this is undoubtedly the case); but unfortunately, in order to be truly effective, it is necessary that such demand shall fall off as the lighting load comes on, for, if the day load overlaps the lighting load, and so increases the peak, extra machinery will be required to meet the demand at this juncture.[1]

It is quite possible that in the provinces, or in any district not subject to the erratic demand due to fogs in the winter-time, such an arrangement might be made. In London, however, it would be very difficult, if not impossible, to so arrange matters that the two loads should not be on at one time, for people who use motors and heating appliances can be scarcely expected to cease doing so because a fog is hanging over the town, and yet it is frequently the case in London that during a fog nearly the whole of the machinery in the works is fully loaded with the lighting load only.

The load factor has a very marked effect upon the cost of supplying electrical energy. The following represents what may be considered the average result of varying the load-factor :—[2]

---

[1] See diagram in section on "Refuse Destructors," for illustration of this.

[2] See paper by Alex. Sinclair, *Mun. Elect. Convention*, 1905.

Load-factor.	Works Cost.	Total Cost.	Cost, including Interest and Sinking Fund.
10	1·30*d*.	1·90*d*.	3·60*d*.
15	·98*d*.	1·42*d*.	2·55*d*.
20	·80*d*.	1·20*d*.	2·10*d*.
25	·70*d*.	1·07*d*.	1·67*d*.
30	·64*d*.	·98*d*.	1·55*d*.
40	·56*d*.	·83*d*.	1·30*d*.
50	·50*d*.	·75*d*.	1·10*d*.

The difference between the load-factors of different kinds of consumption is shown by the typical figures given, which are actual station records.

A.

	Units.	Kilowatts.	Load-factor.
Private consumption . .	926,634	990	10·69
Public lamps consumption	85,765	30	32·64
Tramway consumption .	612,240	170	41·11
Total .	1,624,639	1,190	15·59

B.

	Units.	Kilowatts.	Load-factor.
Private consumption . .	1,274,790	1,103	13·19
Public lamps consumption	217,212	154	16·10
Tramway consumption .	1,085,306	425	29·15
Total .	2,577,308	1,682	17·49

C.

	Units.	Kilowatts.	Load-factor.
Private consumption . .	4,853,384	3,947	14·04
Public lamps consumption	969,702	249	44,46
Tramway consumption .	1,774,988	643	31·51
Total .	7,598,074	4,839	18·90

It is necessary to be precise in measuring the maxima as they may not be simultaneous. An example of this is :—

D.

	Units.	Simultaneous Maxima.	Load-factor.	Separate Maxima.	Load-factor
Private consumption . .	209,166	270	8·84	343	10·33
Public lamps consumption .	99,869	43	26·51		
Tramway consumption .	867,628	418	23·69	520	19·03
Total .	1,176,663	731	17·96		

The following are cases of private and public lighting only :—

E.

	Units.	Kilowatts.	Load-factor.
Private consumption . .	566,255	538	12·02
Public consumption . .	94,916	27	40·13
Total .	661,171	565	13·33

F.

	Units.	Kilowatts.	Load-factor.
Private consumption . .	2,387,331	2,052	13·28
Public consumption . .	205,144	67	34·95
Total .	2,592,475	2,119	13·97

G.

	Units.	Kilowatts.	Load-factor.
Private consumption . .	1,321,353	794	19·00
Public consumption . .	437,996	158	31·65
Total .	1,759,349	952	21·10

Analysis of Costs.—From the foregoing facts it will at once be seen that the class of district and the nature of the demand materially affect the cost of production, and therefore the rate at which electrical energy can be profitably sold. Although it is not possible to alter the character of the district, it is possible to some extent to alter the character of the demand by offering additional inducement to customers to keep down their maximum at the time of heaviest load, and so avoid the sharp and unprofitable peak ; and the manner of doing so has been already dealt with in a previous chapter, and in an exhaustive manner by several other writers.

In analyzing the costs of a works, it is usual to divide them into six heads, as follows :—

(1) Coal.
(2) Oil, waste, water and sundries.
(3) Wages.
(4) Repairs and maintenance.
(5) Rent, rates and taxes.
(6) Management, office and other expenses.

For the purposes of comparison, it is usual to divide the total sum expended on each item during a given period by the number of units sold during the same period, and this is the method of comparison adopted by the *Electric Times* and other technical papers which publish analyses of accounts. Such a comparison cannot, of course, give anything more than a very rough idea of the actual efficiency of any station plant, or system, except in relation to its own or an exactly similar district, and its own or exactly similar local conditions. Obviously a station which in one district shows a given works costs per unit might, if it could be shifted bodily into another and totally different district, show a very different result, although the management, method of running, and output may remain the same. The average costs per unit of London and provincial stations for the years 1896, 1898, and 1904 are as follows :—

YEAR 1896.

	13 London Stations.	68 Provincial Stations.
Coal	1·04	·81
Oil, Waste, &c.	·19	·18
Wages	·57	·76
Repairs, &c.	·41	·34
Works cost	2·21	2·09
Rent, rates and taxes	·31	·23
Management, &c.	·80	·76
Total cost	3·32	3·08

Year 1898.

	17 London Stations.	83 Provincial Stations.
Coal	1·05	·78
Oil, Waste, &c.	·18	·16
Wages	·54	·66
Repairs, &c.	·50	·30
Works cost	2·27	1·90
Rent, rates, and taxes	·34	·22
Management, &c.	·63	·66
Total cost	3·24	2·78

Year 1904.

	25 London Stations.	191 Provincial Stations.
Coal	·82	·70
Oil, waste, &c.	·09	·10
Wages	·27	·37
Repairs, &c.	·31	·27
Works cost	1·49	1·44
Rent, rates and taxes	·22	·16
Management, &c.	·44	·46
Total cost	2·15	2·06

Besides those matters already referred to, and which affect the cost of production as a whole, there are others that affect individual items only.

(1) *Coal.*—If the works is situated near a colliery, suitable coal may be procured at less than half the cost at which it can be obtained in London or other towns at a

distance from the coalfields. Welsh smokeless coal of good quality costs at the pit's mouth about 8*s*. per ton, but the railway charges increase the cost to double that amount by the time it reaches London.

In towns where the smoke nuisance laws are not in force, cheap bituminous coal is consumed very largely, and with good results. In London and some other places smoke is prohibited, and the use of smokeless coal—which is far more expensive than bituminous—is obligatory. Smoke-consuming devices[1] will sometimes get over the difficulty, and enable a lower-priced coal to be used, but, as these arrangements are not always effective, they are not generally adopted. In some parts of the provinces, water for condensing is available, thus enabling the coal consumption to be reduced to a minimum. When water has to be paid for at a high rate, as in London and other towns, cooling arrangements must be provided. In all modern stations feed-water heaters or economizers, or both, are looked upon as a necessary portion of the steam plant, and materially aid in keeping down the coal bill.

Loss of heat by radiation from boilers, steam pipes, feed pipes, valves and engine cylinders, would of necessity be very great if not properly covered, and, as loss of heat means increased consumption of fuel, efficient lagging is essential. Bad draught and careless stoking both mean imperfect combustion and waste of fuel. Ample flue area and a high stack of suitable dimensions are therefore necessary, while the stokers should be men who thoroughly understand their work and are reliable. When there is a strong natural draught, or when forced draught is used, it is advisable to see that there is not too much dust in the coal,

[1] See Smoke Consumers.

or a large portion will probably be carried over into the flues unburnt, or at least only partly consumed. It is generally necessary, and always advisable, to keep a sharp eye on the stokehold and the men engaged there, as the quality of coal and percentage of ash frequently vary,[1] and negligence in this department will probably affect the costs more than it will in any other part of the works. Mechanical stokers are said to effect a reduction in the quantity of fuel consumed, and, when properly managed, small bituminous coal can be used. The weight of all coal delivered should be carefully checked, as well as the temperature of the flue gas and the hot-well and feed-water.

The cost of steam-raising has been largely reduced by close attention to the points enumerated above. For comparison of station results with large factory experience the following particulars given to one of the authors by the engineer of a very large commercial undertaking in the Midlands may be given. Working 168 hours weekly, the cost of steam on the average of forty-six large Lancashire boilers was made up thus:—Conversion of one cubic foot of water into steam: (*a*) standing charges, water, interest, repairs, ·063*d.*, (*b*) labour at 4*s.* 6*d.* per shift, ·034*d.*, (*c*) fuel, for every shilling per ton ·05*d.*, or at 7*s.* 6*d.* per ton the item was ·375*d.* Adding these together, we get ·472*d.* as the total cost of evaporating a cubic foot of water. One 1 h.p. would in a condensing engine cost on this basis, and charging 2*d.* per 1,000 gallons for condensing water, about ·24*d.*, and calculating 1·66 h.p. indicated per unit to ·32*d.* for steam only. The cost of the labour in driving, oil, waste, &c., would have to be added.

[1] See Calorimeter.

(2.) (*a*) *Oil and other lubricants*, (*b*) *water*, (*c*) *waste and sundries*, (*d*) *carbons*.

(*a*) *Oil, &c.*—The cost of oil per unit will depend, amongst other things, upon the quality used, type of plant, design of bearings, whether the lubricators are automatic or hand fed, the provision made for catching waste oil, and the amount of care exercised by the men in charge. In the closed-in type of engine very little waste occurs, and with the open type it is now customary to provide catchers wherever oil can be spilt. These trays or catchers are connected to a pipe system leading to a tank. From the tank it passes through filters and separators, after which it is used over again. Oil of the cheap and nasty type should be carefully avoided both in bearings and cylinders; but, on the other hand, very high-priced oils, while frequently worth the extra price, on account of their greater value as lubricants, are not always as economical in use as their makers claim. It is urged that on account of the higher lubricating value a much smaller quantity is required, and this is no doubt true as far as actual lubrication is concerned; but it must be remembered that the quantity *wasted* will be the same whether it costs 5*s*. per gallon or only 1*s*., and it is not possible to prevent waste taking place.

Solid lubrication for main bearings, crank-pin ends, cross heads, and slides, may sometimes be used with advantage. It is usually applied automatically, the grease being subjected to a pressure of 10 or 15 lbs. per square inch in a cylinder, from which it is conveyed by pipes to the parts to be lubricated. The pressure is maintained by a ratchet or other motor, which slowly forces forward a piston against the grease.

(*b*) *Water.*—The cost of water will depend to a great

extent upon the source of supply. When it has to be bought from a company it may cost anything up to 8*d.* or 9*d.* per 1,000 gallons, and forms a considerable item of the works costs. In such cases even the blowing down of the boilers at frequent intervals, as well as the periodical emptying for examination and cleaning, entails appreciable waste, unless the water can be run into a tank and used again. Radiation from boilers, pipes, &c., of course means condensation and waste of water, as well as coal. In some forms of feed-water heaters, the exhaust steam is allowed to mix directly with the feed-water after passing through an oil separator to extract the oil. In this case a large percentage of the steam is condensed in the feed-water and recovered. When water has to be paid for at a high rate it is sometimes found more economical, particularly in large stations, to sink a tubular well. The cost of pumping will naturally depend upon the depth at which water is found, and therefore from which it has to be lifted. This may be anything from 200 ft. to 500 ft. or more. In London a very large number of tubular wells have been sunk, with the result that there is a perceptible fall in the height of the water, and it is anticipated that in the course of the next twenty years the diminution of the supply may be serious. This is the opinion of experts, and is probably based upon the assumption that the fall will be in direct proportion to the amount of water lifted, but we do not think that this necessarily follows, and it may be that below a certain depth the level may be maintained. Perhaps the most troublesome feature in connection with deep wells is the pump, more especially if sand should be brought up with the water, and with a view to removing the excessive wear which is inherent in moving machinery a form of lift has been introduced

which is operated by means of compressed air. The accompanying illustration (fig. 275) shows the arrangement. A is a small pipe which runs down the well-tube, B. Air under pressure is forced down this pipe, and the water flows up the well-tube and out at the outlet, C. Unfortunately this arrangement is more costly both to put down and operate than ordinary pumping machinery.

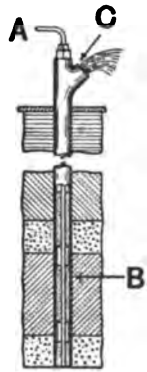

Fig. 275.

(*c*) *Waste and sundries.*—Waste, packing, and other engine-room stores, unless carefully used and watched, amount to a considerable item. Instead of cotton waste for cleaning down the engines, &c., mutton cloths—as they are called—are sometimes used; these, after the oil has been squeezed out of them, can be washed and used over again. A proper system of oil tanks and filters should be provided, and a record kept of the oil used by each driver on each unit of the plant. In a large works a competent storekeeper and a complete system of book-keeping will do much to keep down the cost of waste and sundries.

(*d*) *Carbons.*—Where arc lamps are used for street lighting, it is sometimes difficult to so arrange matters that the whole of the carbons with the exception of two or three inches are consumed, and, unless the trimmers are very careful, or well looked after, the waste will be excessive. In order to ensure a good light, thoroughly good carbons are essential, and the necessity of preventing undue waste all the greater. Cheap carbons of inferior quality can be obtained, but the advantage is very doubtful, taking into consideration the great reduction of light consequent upon their use.

(3) *Wages.*—Next to coal,the wages is the most important item of the works costs, and varies from one-fifth to one-half of the whole, while in or near the colliery districts it is even more important than the coal. The amount of the wages bill will depend upon local conditions, including the capacity and output of the works, the rate of wages paid in the district, and other considerations. It may be taken for granted that in the case of electric lighting, as in every other business, a good workman is worthy of good pay, and it will be found, as a rule, a grave mistake to cut down the wages to a very low figure, and so exclude good workmen, who would more than make up to the undertaking the extra wages paid them.

(4) *Repairs and maintenance.*—Under this head should be included the whole of the costs incurred in keeping the buildings, plant, and mains in thorough and efficient working order, renewing broken or worn-out parts, &c. The amount expended will depend upon the class of machinery and buildings, the quality of the cable, &c., and method of laying, as well as upon the efficiency of the supervision and working staff.

(5) *Rent, rates, taxes, &c.*—Over these items the engineer can exercise but little control, the rates and taxes being fixed by the assessors. As regards the first item of rent, it is always advisable, as stated in a previous chapter, to purchase all property outright if possible, in which case the item disappears.

Management, &c.—This includes secretarial and office expenses, managers and engineers' salaries, directors' fees, legal expenses, insurance, &c. The first four items (1 to 4) are commonly called 'works costs,' as distinct from the two latter, which are practically standing charges.

Costing.—A convenient method of apportioning costs for the purpose of prime-costing, which should be carried out systematically and regularly, is to adopt the decimal system as advocated by Dewey [1] and Chase,[2] utilizing as a basis the side-head numbers [3] given by the Board of Trade in the model form of accounts.[4] This has been worked out in practice by one of the authors with very satisfactory results on the following standing schedule for repairs. By this means the annual cost of maintaining each unit of plant is readily and simply obtained, which is of great service to the managing engineer in reducing costs.

A 1, Coal and cost of unloading.
A 3, Generation wages.
A 41, Repairs, buildings : offices.
A 42, ,, ,, works.
A 43, ,, ,, stores.
&c.
A 21, Lubricating oil.
A 22, Waste and mutton cloths.
A 23, Water.
A 24, Packings and steam jointing.
A 25, Boiler fluid.
&c.
A 50, Repairs, steam pipes.
A 51, ,, No. 1 engine.
A 52, ,, ,, 2 ,,
A 53, ,, ,, 3 ,,
A 54, ,, ,, 4 ,,
&c.
A 60, General dynamo repairs.
A 61, Repairs, No. 1 dynamo.
A 62, ,, ,, 2 ,,

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[1] Melvil Dewey, "Decimal Classification and Relative Index," Library Bureau, Boston.

[2] W. L. Chase, "A General Engineering Classification and Index," *Trans. Amer. Soc. Mech. Engrs.*, vol. xiv. July, 1893.

[3] Board of Trade model form of accounts headings :—A 1, coal; A 2, oil, &c.; A 3, wages in station; A 4, repairs, buildings; A 5, repairs, engines and boilers; A 6, repairs, dynamos; A 7, repairs, auxiliaries, instruments and tools; B 1, wages, linesmen; B 2, repairs, mains; B 3, repairs, apparatus on consumers' premises; B 4, repairs, substations; C 1, trimming, &c., public lamps; C 2, renewals, ditto; D, royalties; E 1, rents: E 2, rates and taxes; F 1, office salaries; F 2, stationery and printing; F 3, general establishment charges; G, law expenses; H, depreciation; G, special charges.

[4] Obtainable from Messrs. Eyre & Spottiswoode, at 6*d*. per copy.

A 63, Repairs, No. 3 dynamo.
A 64, „ „ 4 „
&c.
A 570, Repairs, flues.
A 571, „ No. 1 boiler.
A 572, „ „ 2 „
A 573, Repairs, No. 3 boiler.
A 574, „ „ 4 „
&c.
A 70, Repairs, switchboards.
A 711, „ rectifier, No. 1.
A 712, „ „ „ 2.
A 713, „ „ „ 3.
&c.
A 72, Repairs, works, motors.
A 73, „ „ fans.
A 740, „ injectors.
A 741, Repairs, feed-pumps.
A 750, „ tanks.
A 751, „ sand filter.
A 752, „ cloth „
A 753, „ softener.
A 754, „ feedwater heater.
A 755, „ economizer.
A 756, „ conveyor.
A 760, General repairs, condensers.
A 761, Repairs, Brush condenser.
A 762, „ Allen „
A 763, „ Körting „
A 764, „ Bertram „
&c. &c.
and so on for mains, transformers, &c.

For the methods of costing-keeping the reader is referred to an excellent little volume which has been found to contain a workable and satisfactory system without complication, "Cost Accounts," by L. Whitten Hawkins (Gee & Co.). Other papers and references are given below which will be found very useful for guidance in arranging a costing-system.[1] The engineer should take this in hand, as the tendency of accountants is to evolve an unnecessary elaborate scheme which too often involves labour incommensurate with the value of the results obtained, and pay more attention to the means than to the end sought. For the

[1] "Workshop Costs," by S. and F. Pearn, and "Engineering Estimates and Cost Accounts," by F. G. Burton (Technical Publishing Company, Ltd.); "Factory Accounts," by Garcke & Fells, and "Engineering Estimates, Costs and Accounts" (Lockwood); "A Short Way to keep Time and Cost," H. L. Binsse, *Trans. Amer. Soc. Mech. Engrs.*, vol. ix. p. 380. Nov., 1887. "Management for Workshops," C. V. Carpenter, *Engineering Magazine*, July and Aug., 1902.

purpose of the engineer an accuracy to 5 per cent is quite sufficient.[1]

It is very important that the book-keeping should be such as will enable the standing and running costs to be separated, and probably the best and most useful results in this direction will be obtained by employing the analysis used by Mr. Arthur Wright for his stations.[2]

Depreciation.—Most municipal undertakings charge depreciation [3] against surplus profits; a few follow the custom of companies and include it as a debit in expenses on revenue account. The allowances made by three typical stations adopting the former method are as follows:—

	Bolton. Per cent.	Glasgow. Per cent.	Aberdeen. Per cent.
Lands and buildings	—	1	1
Machinery	6	5 and 7½	5
Mains	6	2½	1½
Transformers	6	—	—
Accumulators	10	7½	5
Meters	10	6	5
Motors	10	—	—
Instruments	10	5	2½

Records.—To enable the station engineer to ascertain from day to day the expenses incurred, and the cost per unit, a simple but comprehensive system of forms and reports is usually adopted.[4] This should include such

[1] See remarks by J. B. Bardsley, "Hints to Students in Devising Systems of Engineers' Cost Accounts," April, 1902 (Gee & Co.).

[2] *Journ. Inst. Elect. Engrs.*, vol. xxvi. p. 451, Dec. 1901.

[3] "Depreciation, Reserves, and Reserve Funds," by L. R. Dicksee (Gee & Co.), and "The Depreciation of Factories, Mines, and Industrial Undertakings and their Valuation," by Ewing Matheson, M. Inst. C. E. (Spon).

[4] See *Electric Lighting Accounts*, by G. Johnston (Gee & Co.); *Central Station Management and Finance*, by Mr. H. A. Foster, and a paper by Mr. A. B. Mountain on "Electricity Works Records"; *Proceedings of the Municipal Electrical Association*, 1896; Robert Hammond on "The Cost of Generating and Distributing Electric Energy," *Journ. Inst. Elect. Engineers*, March, 1898.

as may be necessary to embody the various matters which from time to time are dealt with by each department or section. By summarizing these, the state of the business may periodically be ascertained, and the position financially gauged, while a constant check is kept upon the running costs and efficiency of operation. As some guide to the class of forms needed, a sample of a daily report sheet is given in fig. 277, and the ruling of an engine-room log-book in fig. 276. There are a number of useful card index systems now in use for keeping records, prime costing, &c., and all these seem to answer the purpose admirably, while being much simpler and more convenient than many systems of book-keeping. The subject has, however, been treated more fully by various writers, and we must refer our readers to their works.[1]

Curves are very convenient and useful, especially for recording the tests of plant, both steam and electrical. Fig. 278 gives, as an example, the curves showing the performance of a revolving magnet 500 kilowatt direct-coupled single-phase alternator of modern design. The curves are self-explanatory, showing the saturation or relation of terminal volts to exciting currents, the iron loss at different loads, the short-circuit ampères and kilowatts generated with different fixed currents; from these all the particulars required as to electrical performance are obtainable.

Staff, Workmen, and Duties.—The number of men required to properly run the machinery in a central station varies with the system, size of station, and other conditions, as well as the ideas of the engineer. If the works is over-

[1] *Electrical Review*, vol. xlviii. p. 483, March 22nd, 1901, and paper by J. Charles Osborne, "Card Indexing and Filing," *Trans. Civil and Mechanical Engineers' Society*, May 4th, 1905.

Date, ______ ______ ___ 189

STATION

TOTAL.	E.E. Amps.	TIME. m.	ALTERNATORS.											INCANDESCENT CIRCUITS														ARC				
			0	1	2	3	4	5	6	7	8	9	10	1A	1B	1C	1D	2A	2B	2C	2D	3A&B	4A	4B				1	2	3	4	5

Fig.

LOG BOOK.

Date, ... 189

Circuits										Volts		Boilers																		Remarks
6	7	8	9	10	11	12	13	14	15	a.m.	p.m.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	

76.

[To face p. 457.

ELECTRICITY DEPARTMENT.

Engine Room Report for ______________________ 189

	Total	Per Unit Generated.
Coal consumed		
Oil consumed		
Water consumed .. .		
Pounds Water evaporated per lb. of fuel =		

Engine Room Stores used.	
Oil Cylinder	
,, Engine	
,, Dynamo	
,, Blast	
,, Paraffin	
Grease	
Waste	

	Incandescent.	Arcs.	Total.
Units generated, Night ..			
Do. do. Day ..			
Do. do. Heavy ..			
Total			
Units used in Works ..			
Units delivered to Mains ..			

Arcs on	p.m.
,, off	a.m.
,, hours	
Maximum load	amps.
,, ,,	k w
Minimum ,,	k.w
Ratio $\frac{\text{Heavy.}}{\text{Day + Night.}}$	

Load Factor			
1	Average hours per day of max. load	$= \frac{\text{Units generated.}}{\text{Max. K W load}} =$	hrs.
2	Crompton Load Factor for day	$= \frac{\text{Units generated}}{\text{Max. K.W.} \times 24} =$	%
3	Mean load in K.W	$= \frac{\text{Units generated.}}{24} =$	k.w
4	Plant Load Factor	$= \frac{\text{Units generated.}}{\text{Plant capacity} \times 24} =$	%

Boilers	1	2	3	4	5	6	7	8	9	10	Total.
Boilers steaming ..											
Hours run											
Commenced run											
Duration run to date ..											

Engines	1	2	3	4	5	6	Total Engine Hours.
Hours run							

Rectifiers	1	2	3	4	5	Total Rectifier Hours.
Hours run.						

Repairs effected

Remarks

____

Fig. 277.

manned the wages bill becomes excessive, while, on the other hand, an inefficient staff may result in an unsatisfactory supply, and in the event of an accident to an

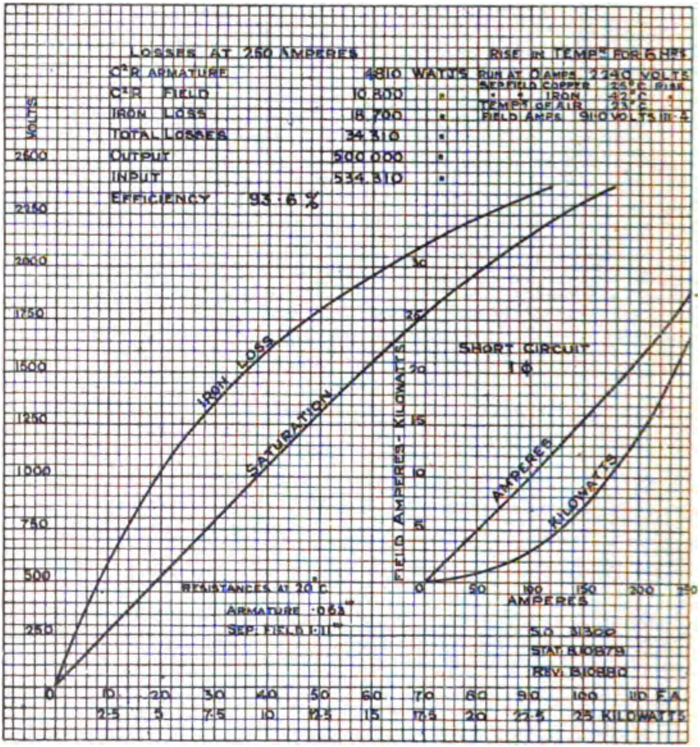

Fig. 278.

employé serious allegations may be brought against those in authority.

When the supply is on the continuous-current system a storage battery capable of taking the load during the

small hours of the morning will enable the machinery to be shut down and the works closed, thus dispensing with one shift of men. Occasionally, two shifts of twelve hours each have been tried, but in addition to the obvious objection of so over-working the men, very little is gained by so doing, as overtime is invariably paid at an increased rate, and the work cannot be as well looked after during the last four hours by those who have already worked eight hours as it can by men who have just come on duty. As a rule, therefore, the day is divided into three shifts of eight hours each, and, as each shift has to be worked without interval, and for seven days in the week, it is probably quite as long as any man can be reasonably expected to work, more particularly as the stokehold and engine-room are only too frequently most uncomfortable places in which to work, on account of the high temperature.

The inside staff includes those actually engaged in running or looking after the generating plant, and the outside staff those dealing with distribution and street lighting, &c. These may consist of :—

Inside Staff.	*Outside Staff.*
(*a*) Works Manager.	(*a*) Distributing engineer.
(*b*) Charge or shift engineers.	(*b*) Mains engineer and assistants.
(*c*) Assistant charge or shift engineers or switchmen.	(*c*) House-wiring inspectors.
(*d*) Fitters.	(*d*) Test-room attendants, or testing electricians.
(*e*) Engine-drivers.	(*e*) Road foremen or cable foremen.
(*f*) Dynamo attendants or greasers.	(*f*) Lamp-trimmers.
(*g*) Stokers.	(*g*) Jointers.
(*h*) Coal-trimmers.	(*h*) Bricklayers.
(*i*) Cleaners.	(*i*) Carpenters.
(*j*) Labourers.	(*j*) Labourers.
	(*k*) Watchmen.

The clerical and office staff may comprise:—

(a) Book-keeper.
(b) Draughtsmen.
(c) Clerks.
(d) Timekeeper.
(e) Storekeepers.
(f) Messengers.

Their duties may be given briefly as follows:—

GENERATION DEPARTMENT.

(a) *Works Manager.* -To take entire charge of the power-station and staff.

(b) *Charge or shift engineer.*—To generally superintend the running of the plant during a shift, and to be responsible to the assistant engineer. To give all necessary instructions to the engine-drivers, stokers, and other men engaged on the same shift. To enter up the report book and daily report sheets, load curves, &c.

(c) *Assistant charge or shift engineer.*—To do all switching, regulation pressure, paralleling, &c., to enter up the log-book, and to act under the instructions of the charge engineer.

(d) *Fitters.*—To keep all plant in thorough repair and working order to the instructions of the assistant engineer and under the superintendence of the charge engineers.

(e) *Engine-drivers.*—To drive the engines to the instructions of the switchboard attendants.

(f) *Dynamo attendants and greasers.*—To look after the lubrication of dynamos and engines, and assist the engine-drivers, if necessary.

(g) *Stokers.*— To fire the boilers and be responsible for them and the steam pressure.

(h) *Coal-trimmers.*—To assist stokers and trim out coal for their use.

(i) *Cleaners.*—To clean the engines, dynamos, &c., as well as the engine-room, &c.

(j) *Labourers.*—To attend to boiler-cleaning and other work under supervision.

DISTRIBUTION DEPARTMENT.

(a) *Distributing Engineer.*—To take entire charge of the mains and distributing system, and all road and street works, and the out-door staff.

(b) *Mains engineers and assistant mains engineers.*—To generally superintend the repairs on existing mains, services, &c., and to instruct men engaged on outside work under the supervision of the distributing engineer.

(*c*) *House-wiring inspectors.*—To inspect wiring on consumer's premises, connecting on, &c.

(*d*) *Test-room attendants.*—To test all meters, transformers, and instruments, before fixing, and to be responsible for all testing of mains, dynamos, &c.

(*e*) *Road foreman.*—To superintend excavation, laying of conduits, erection of lamp columns, relaying of paving, and to take charge of labourers, gangers, &c.

(*f*) *Lamp-trimmers.*—To trim all street arc lamps and keep them clean. A mechanic may be engaged to execute the necessary repairs, or these may be carried out by the trimmers themselves, depending upon circumstances.

(*g*) *Jointers.*—To do all cable-jointing on mains, services, street lamps, connecting up meters, &c.

(*h*) *Bricklayers.*—To construct street boxes, transformer chambers, and similar work when required.

(*i*) *Carpenters.*—General carpenters' work, fixing meters, consumers' terminal boxes, &c.

(*j*) *Labourers.*—General excavation and street work, putting in cable, &c.

(*k*) *Watchmen.*—Watching street work at night, and on Sunday, keeping signal lamps alight, &c.

THE CLERICAL DEPARTMENT.

(*a*) *Bookkeeper.* – Keeping all account books, wages books, &c

(*b*) *Draughtsman.*—To execute all plans and drawings of plant, mains, extensions, &c., and maps.

(*c*) *Clerks.*—General clerical work.

(*d*) *Timekeeper.*—To keep the time of all the men, to answer inquiries and keep the door.

(*e*) *Storekeeper.*—To receive, keep, and give out, and be responsible for, the stores, to enter up all stores books, &c.

(*f*) *Messengers.*—To run errands, &c.

Refuse Destructors.—To thoroughly grasp the theory of the destructor, it becomes necessary to glance over its history, and at the same time observe the changes in the general conditions under which it works. Without attempting an historical *résumé*, we may mention that the birth of the modern destructor occurred about 1877, by its introduction at Birmingham, Leeds, and Manchester. During the ensuing ten years, the example of these towns was followed by so many

others, and the satisfactory disposal of refuse became literally such a burning question, that the Local Government Board instructed one of their engineering inspectors, Mr. Thomas Codrington, M.Inst.C.E., in 1888, to prepare an elaborate report bearing on the whole subject. This report was not only at the time of the greatest value in itself, but it still stands pre-eminent among the literature that has since been issued to the public.

Further information will be found in some form in one or other of the following pamphlets:—

Report on "Destruction of Towns' Refuse," by Thomas Codrington, Engineering Inspector to the Local Government Board (1888).

Transactions of the International Congress of Hygiene and Demography at London, 1891. Vol. vii., section vii.

Reports of Select Committee of House of Commons on Destructors in connection with Kensington Vestry Bill. (February and March, 1887.)

Report on Refuse Disposal to the Commissioners of Sewers of the City of London, by Dr. Sedgwick Saunders. (January, 1881.)

L.C.C. Report on Dust Destructors. (1893.)

Lord Kelvin's Report on Tests of the Horsfall Destructor.

F. Goodrich's Treatise on Refuse Destructors.

Charles Jones' volume on Refuse Destructors.

W. P. Adams on "The Combination of Dust Destructors and Electricity Works Economically Considered," *Institute of Electrical Engineers' Journal*, December, 1904.

A dust destructor should theoretically fulfil the following conditions:—

(*a*) It should be capable of destroying by fire all of what is combustible in towns' refuse without the addition of any fuel of higher calorific value.

(*b*) The solid products of combustion (clinker, ashes) should consist solely of the incombustible portions of the refuse and be completely sterilized, whereas the gaseous products of combustion must be not only sterilized thoroughly but free from objectionable smell and admixture with solid particles.

Considerable care has to be exercised in the choice of site for destructors, for not only have financial and constructional difficulties to be dealt with, but the sentiments and objections of the neighbours and adjoining landowners have also to be considered. Financial troubles generally arise because the destructor should theoretically be situated at the centre of the district whose refuse it is to treat, and land in populous towns is commonly expensive. It therefore becomes simply a

question of £ *s.* *d.* as to whether it is cheaper to plant a depôt in the less costly outskirts of a town and pay the extra cost of cartage, or to buy a valuable piece of ground in its centre and save the extra haulage. Clearly this is a matter which will have to be decided for each particular case, and for which no general rule can be laid down, but it should be mentioned that, perhaps, there is a growing tendency to keep refuse yards in the centre of their districts.

It was found that refuse could be burned under forced draught at a high temperature, and the flue gases carried off sufficient heat to evaporate water at a useful pressure in a boiler through which such gases were passed. This led to the conjunction of destructors and electricity works, and, despite the objections to the combination arising from the presence of dust, there are a large number of combined stations at work giving very successful results.

The destructor consists essentially of a firebrick-lined furnace with feeding doors and a grate provided with forced draught, this being obtained either by means of a fan (often electrically driven) or steam jets below the bars. The refuse may be fed in from the top through hoppers, as in the Fryer and Horsfall, or fired like coal through the front doors, as in the Meldrum and Heenan and Froude patterns. From the furnaces the gases pass into a main flue and thence through the tubes of a Lancashire or round the tubes of a Babcock-Wilcox boiler, being cleansed of their fine gritty dust particles by a centrifugal catcher or other means, and thence being discharged at a high elevation by the chimney-stack.

The temperature fluctuates so largely during the operations of incineration, feeding, and clinkering, that it is necessary to provide the boiler or boilers for, say, 200 lbs. for a working pressure of 150 or 160 lbs. per sq. in., the connection to the engine main steam range being made through a reducing valve.

A great deal of discussion has taken place, and varied opinions are held, as to the advisability and efficiency of the combination of electricity works and destructors, and there is no doubt that many optimistic prophesies, such as that indulged in some twenty years ago, when it was stated that by burning the refuse of a district one 8 c.-p. lamp could be lighted per inhabitant therein, cannot be reasonably anticipated to be fulfilled. The general experience has been that small stations or larger ones in their initial stages do derive some, and probably a material advantage, from the cheap steam so obtained, provided that such steam is handed over to the electricity department, either free or at a nominal price, as a by-product. Some metropolitan stations,

however, are called upon to pay as much as it would cost to raise the same amount of steam by coal-fired boilers, in which case the value of the combination is exceedingly doubtful.

Several of the provincial undertakings are now utilizing existing, or have constructed new refuse destructors, as auxiliary means of generating steam, and give the labour for up-keep of boilers or management of the destructor in return for such service. Thus, while the expectations of those who foresaw in the destructor a means of rendering electricity a remarkably cheap manufactured product were necessarily doomed to disappointment, the success of carefully-considered schemes for the auxiliary use of refuse-raised steam has shown that, under suitable conditions, it is quite possible to make use of the heat which would otherwise be wasted or turned to less account.

Generally speaking, it may be said that refuse has one-tenth the calorific value of coal as a steam-raising agent, and that if coal will evaporate 10 lbs. of water, refuse, weight for weight, will evaporate 1 lb. The average units produced per ton of refuse burned are about twenty to thirty under working conditions over long periods; double these figures are now frequently claimed, while on short test runs under exceptionally favourable conditions over 100 units per ton have been obtained. A great deal depends upon the kind of use made of the destructor; regular firing throughout the twenty-four hours without intermission obviously giving the best results owing to the reduction of radiation losses and the general high temperature attained and maintained. The best practice is to employ the destructor to provide a regular supply of steam and to add coal-fired boilers for the peak-loads. It is thus possible to continue the use of comparatively inefficient steam engines and save the charge incident upon "scrapping" them, which would otherwise be the only commercial course to pursue in face of the improvements which have been made in prime movers in the last few years.

The diagram, Fig. 279, gives the load curves for the day of heaviest output of a provincial station during the past two years, and shows by the hatched portion what could be done to save coal firing assuming the auxiliary destructor plant operated sixteen hours daily. By continuing the use over the twenty-four hours a still greater service would be rendered, provided that, say, an average of 50 to 60 tons of refuse could be collected daily and that it was steadily burned without intermission. Refuse must be got rid of in any case, the question to consider in any given instance is whether the value of the steam thus produced will or will not be greater than the extra cost of working the destructor

so as to meet the requirements of steam consumption over and above what would be necessary for its proper and efficient disposal on sanitary grounds. It is often urged, and with good reason in many instances, that the most suitable site for a destructor is not that best adapted for electricity generation, and therefore that instead of taking the destructor to the central station the less efficient plant in the latter

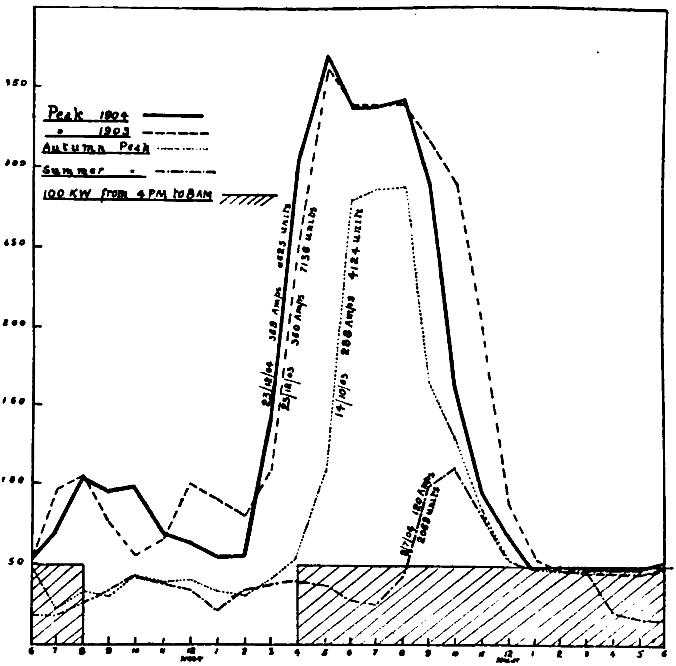

Fig. 279.

should be laid down at the destructor and operated as an independent and auxiliary generating station. The deciding factor in this case will probably be labour, but it must be remembered that where coal is cheap labour will also be cheap, while the value of the heat from a destructor or peak-load will be comparatively small, unless the combination can be so worked as to reduce the standing boiler-house charges for lighting-up and banking fires. In any case a destructor plant, when auxiliary to

the main station, must be worked so as to carry a portion of the load over the winter peak, otherwise the standing charges—by far the heavier of those incurred—will be unaffected. Of course, these considerations do not enter into the argument where the combined station is of such a size that the destructor can supply the whole of the steam required and the peak-load is under, say, 300 kilowatts, as is the case in many of the provincial undertakings where the combination is regarded, and rightly so, as a success.

It is unnecessary to enter in this volume into the details of destructor furnaces, as they are very fully described in the special treatises devoted to the subject, and the electrical engineer is more concerned with the steam produced than the sanitary aspect of the question.

APPENDICES

APPENDIX A

FATALITIES IN EUROPE DUE TO ELECTRIC SHOCK 1880–1889

(SEE CHAPTER I.)

Date	Victims.	Place where killed.	Cause of death.
1880	M. Bruno . .	Aston	Jablochkoff alternating current
,,	A stoker . .	Yacht, *Livadia* .	Jablochkoff alternating current
1881	A workman .	Hatfield . . .	Brush current under 800 volts
1883	Railway official	Pesth	Ganz alternating current
1884	Emile Martin	Tuileries Garden, Paris	Siemens 12-light alternator
,,	Jos. Kenarec		
,,	H. Pink . . .	Health Exhibition, London .	1,000-volt Hochhausen machine
,,	W. Moore . .	Middlesbrough .	Arc light plant, high voltage and bad insulation
1887	R. Grove . .	Regent Street, London	Alternating current, Grosvenor Gallery
,,	J. Williams . .	Risca, Wales . .	Shock from electric-lighting wire
1888	A workman. .	Terni, Italy . .	Alternating current
,,	A carpenter .	Valladolid, Spain	Alternating current
,,	An attendant .	,, ,,	Killed trying to save his companion
,,	E. A. Richardson	Consett Iron Works	Current from arc light plant
,,	A workman .	Brighton . . .	Touched a live wire on roof of brewery
1889	I. Connelly . .	Siemens, London	Alternating current of 1,000 volts.

ACCIDENTS DURING FOURTEEN YEARS IN ENGLAND, 1892–1905.

Date	Victims.	Place where killed.	Cause of death.
1892	Tradesman's assistant .	(Consumer's premises) Chatham	Defectively insulated cables
,,	Jointer's mate .	(Street) Kensington, London	Failure to use gloves provided
1893	Switchboard assistant . .	(Switchboard) Brighton	Imprudently operating switch
,,	Workman . .	(Sub-stn.) Blackfriars, London	Attempting to remove workman from contact with h.t. bus bar
1894	Unskilled workman	(Sub-stn.) Blackfriars, London	Accidental contact with h.t. bus bar
,,	Workman . .	(Central station) Prescot	Contact with h.t. voltmeter wire
,,	Workman . .	(Cen. stn.) Bankside, London	Contact with charged metal usually out of reach
,,	Assistant . .	(Central station) Taunton	Careless use of oil-can near alternator
1895	Workman . .	(Sub-stn.) Bristol	Cleaning live fuses ungloved
,,	Workman . .	(Sub-stn.) Cheltenham.	Accidental contact with unprotected h.t. terminal
1896	Contractor's official . . .	(Cen. stn.) Hampstead, London	Accidental contact at back of switchboard
,,	Workman . .	(Sub-stn.) Bedford	Breaking earth connection of transformer.
1897	Workman . .	(Factory) Newcastle-on-Tyne	Contact with arc circuit of 3,000 volts
,,	Workman . .	(Sub-stn.) Hampstead, London	Defective earthing of transformer case
,,	Workman . .	(Works) Bournemouth	Making repairs; 2,000 v.
,,	Workman . .	(Switchboard) Bristol	Screwed into live cable
1898	Foreman . .	(Transformer Pit) Chelsford	Failure to use gloves when disconnecting
,,	Wireman . .	(Works) Rathbone Place	Contact with 1,000 v.
,,	Wireman . .	(Mains) Southampton	Repairing h.t. joint not using gloves.
1899	Foreman cable jointer . . .	(Sub-stn.) Bolton	Disconnecting transformer

ACCIDENTS DURING FOURTEEN YEARS IN ENGLAND, 1892-1905 (*cont.*).

Date.	Victims.	Place where killed.	Cause of death.
1900	Jointer . . .	(Sub-stn.) Cheltenham)	Testing transformers
,,	Assistant engineer	(Central stn.), Newport)	Switching
,,	Assistant engineer	Manchester Sq. Stn., Metropolitan Co.	Making connection, switchboard
,,	Carpenter's mate . . .	Blackheath Central Stn.	Touched a bolt at switchboard
,,	Miner . . .	Colliery near Coventry	Fell upon a motor; 450 volts
1901	Miner . . .	Southall Colliery	500 volts
,,	Assist. Switchman	Deptford, transformer room	Fell against a live fuse; 10,000 volts
,,	Two men labourers . .	Palmer's Works, Jarrow	In motor-house against orders; 410 volts
,,	Workman . .	Exhall Colliery, Warwickshire	Live wire broke
,,	Electrician . .	(Sub-stn.) Chatham	Attending to wires
1902	Workman . .	Alhambra, Sheffield	Shock from bracket; 200 volts
,,	Engineman. .	Glapwell Colliery, Derbyshire	Touched a wire; several thousand volts
,,	Workman . .	Yarmouth	Changing globe of arc lamp; 700 volts
,,	Collier . . .	Philadelphia Colliery, Durham	Shock from broken cable
,,	Workman of Callender & Co.	Sutton Coldfield Corporation	Repairing feeder pillar; 235 volts
,,	Fitter . . .	Metropolitan Company, Manchester Sq.	Handling copper strip which touched live cable
,,	Lamp trimmer	Harrogate Corporation	Touched live switchbox without gloves
,,	Workman . .	North Eastern Steel Works, Middlesbrough.	Touched live wire
1903	Two men . .	Fulham Borough Council public baths	Leakage in wiring; 200 volts
,,	Two boys . .	Colliery, Coatbridge	Touched signal wires making contact with live wires

ACCIDENTS DURING FOURTEEN YEARS IN ENGLAND, 1892-1905 (*cont.*).

Date.	Victims.	Place where killed.	Cause of death.
1904	Boy	London Electric Supply Co.	Cleaning terminal without orders; 10,000 v.
,,	Switchman . .	Charing Cross and City Co., Stratford	Removing fuses
,,	Ironworks labourer . . .	Acklam Ironworks	Grasped at electric lamp to save fall
,,	Labourer . .	Metropolitan Electric Supply Co.	Cutting pipe; current on at time; no gloves used; 500 volts
,,	Engineer . .	Walker-on-Tyne	Came into contact with brushes; 300 volts
,,	Colliery employé . . .	Ferryhill, Durham	Grasping bare signal wire; 220 volts
,,	Sub-station employé . . .	Scarborough Electric Light Co.	Dusting switches with gloves on; found dead with head 3 in. from nearest terminal; 130 volts.
,,	Miner. . . .	Eldon Colliery, Bishop Auckland	Grasping electric cable supplying current to coal-cutting machines
1905	Clockwinder (weak heart)	Leeds Market Hall clock tower	Clock gong operated by current from lighting mains; 200 volts alternating
,,	Foreman electrical engineer	Bolckow, Vaughan & Co., Middlesbrough	Searching for leakage touched live wire
,,	Electric pump driver . . .	Colliery at Tredegar	Fuse nipped between lid and case of c.i. fuse box; ineffective earthing
,,	Senior shift engineer . . .	Islington electricity works	Adjusting rectifier, 1,500 to 2,000 volts; no gloves used
,,	Bricklayer's labourer . . .	Gateshead Railway shops	Grasped wire presumably to prevent falling
,,	Master electrician	Kennington	Cut wire with pliers when current on; earth damp; nails in boots; 200 volts
,,	Workman . .	Tube Works, Airdrie	Found dead across iron rail guarding electric switch of scarfing machine

ACCIDENTS DURING FOURTEEN YEARS IN ENGLAND, 1892-1905 (*cont.*).

Date.	Victims.	Place where killed.	Cause of death.
1905	Electrician . .	Neasden Power Station	Entangled among live wires in transformer chamber; instructions not to enter; 11,000 volts
,,	Bricklayer . .	District Railway sub-stn., Whitechapel	Removing floor-plates in sub-station; assumed plate caught on feeder switch
,,	Electrician . .	Hastings Tramways	Accidentally brought his hand into contact with live part of switch
,,	Electrician . .	Hammersmith	Removing ammeter; did not wear gloves; 2,500 volts

APPENDIX B

DEFINITIONS OF TERMS EMPLOYED IN PROVISIONAL ORDERS, &c.

Energy (*electrical*) $= C \times E \times T = EQ = PT$. Units: Joule ($10^7$ ergs), Watt-hour (3,600 Joules), Board of Trade Unit or "Unit," for which names "Kelvin" and "Bot" have been suggested (1,000 watt-hours). For the purposes of Provisional Orders, &c., electrical energy is deemed an agency within the meaning of "electricity" as defined in the Electric Lighting Act, 1882, wherein the expression "electricity" means electricity, electric current, or any like agency. (Section 32, 45 and 46 Vict. chap. 56, 1882.)

Power (*electrical*) $= C \times E$. Units: Watt (10^7 C.G.S. units), kilowatt (1,000 watts). The rate per unit of time at which energy is supplied.

Works: Includes electric lines, also any buildings, machinery, engines, works, matters or things of whatsoever description required to supply electricity.

Electric line: A wire or wires, conductor or other means used for the purpose of conveying, transmitting, or distributing electricity, with any casing, coating, covering, tube, pipe, or insulator enclosing, surrounding, or supporting the same or any part thereof, or any apparatus connected therewith, for the purpose of conveying, transmitting, or distributing electricity or electric currents.

Main: Any electric line which may be laid down by the undertakers under a Provisional Order, License, or Special Act in any street, subway, or public place, and through which energy may be supplied or intended to be supplied by the undertakers for the purpose of general supply.

Distributing main: The portion of any main which is used for the purpose of giving origin to service lines for the purpose of general supply.

Service line: Any electric line through which energy may be supplied or intended to be supplied to a consumer either from any main or directly from the central station.

General supply: The supply of electrical energy generally to ordinary consumers; does not include the supply of energy to any one or more particular consumers under special agreement.

Earth: A metallic body is efficiently connected with earth when it is connected with earth in such a manner as ensures at all times an immediate and safe discharge of electrical energy.

Area of supply: The area within which for the time being any

company, body, or person is or are authorized to supply energy under Parliamentary powers.

Subway: Any passage or covered way under the surface of a street constructed for the reception of pipes or wires.

Consumer: Any body or person supplied or entitled to be supplied with energy.

Consumer's terminals: The ends of the electric lines situate upon any consumer's premises, and belonging to him, at which the supply of energy is delivered from the service lines. The pressure here must not exceed 250 volts.

Undertakers: Any company, body, or person authorized to supply electrical energy under the powers of a License, Provisional Order, or Special Act.

Consumer's wires: Any electric lines on a consumer's premises which are connected with the service lines of the undertakers at the consumer's terminals.

Aerial line: Any electric line which is placed above ground, and in the open air.

Pressure: The difference of electrical potential between any two conductors through which a supply of energy is given, or between any part of either conductor and the earth.

Low pressure: Where the conditions of the supply are such that the pressure at the consumer's terminals does not exceed 250 volts, the supply shall be deemed a low-pressure supply.

Medium pressure: Where the conditions of the supply are such that the pressure between any two conductors or between one conductor and earth may at any time exceed 250 volts, but does not exceed 650 volts, the supply shall be deemed a medium-pressure supply.

High pressure: Where the conditions of the supply are such that the pressure may exceed 650 volts, but does not exceed 3000 volts, the supply shall be deemed a high-pressure supply.

Extra high pressure: Where the conditions of the supply are such that the pressure may exceed 3000 volts, the supply shall be deemed an extra high-pressure supply.

Public purposes: The lighting of any street or any place belonging to or subject to the control of the local authority, or any church or registered place of public worship or any hall or building belonging to or subject to the control of any public authority or any public theatre.

Private purposes: Any purposes whatever to which electricity may for the time being be applicable, not being public purposes, except the transmission of any telegram.

APPENDIX C

——— ELECTRIC LIGHTING ORDER, 18—

Description of System of Supply (Low Pressure).

1. The electric pressure between each pair of poles in consumer's premises to be 110 volts.

2. At each of the generating stations the negative pole of each and all of the dynamos, and the negative of each pair of feeding mains will be connected together. The positive pole of any dynamo may be connected at will with the positive pole of any pair of supply mains, or the whole of the dynamos may be arranged in simple parallel with the feeding mains.

3. The feeding mains will be run direct (i.e. without being tapped for distribution of the current) from the engine-room to the various distributing points, say, 300 yards or more from the generating station.

4. The pressure at the distributing points will be kept constant by regulating the pressure at the engine-room so as to compensate for the loss in potential in the feeding mains.

5. A continuous service will be provided by means of the dynamos running direct on the feeding mains during the hours of greatest demand, and for the present by means of accumulators at the generating stations during the hours of least demand.

6. It is intended in the future to place batteries of accumulators at the various distributing points instead of at the generating stations.

7. When the demand for electricity increases it may be necessary to use the 3-wire system between the generating stations and the distributing points. Under these circumstances, as the charging pressure for accumulators will be at least 140 volts, there may be a difference of potential of 150 volts between each two wires of the 3-wire system (i.e. 300 volts in all).

8. In the last paragraph the 3-wire system is specified only for use between the generating station and the distributing points, but it may be necessary for certain large consumers situated at some distance from the distributing points to extend the 3-wire system from the distributing points to the consumer's premises.

——— ELECTRIC LIGHTING ORDER, 190-

Description of System of Supply (High-pressure Alternating).

1. A high-pressure alternating current supply at a frequency of — complete periods per second at constant pressure to transformers,

placed as a rule in converting stations, or in street boxes, but in some instances, where this is impracticable, on consumer's premises.

2. Sub-stations will be either

(a) Suitable buildings acquired for the purpose, or
(b) Underground constructions, or
(c) Other constructions specially approved by the Board of Trade.

The sub-stations will be erected above ground wherever possible, but where necessarily underground they will be constructed in accordance with plans submitted to the Board of Trade, and the maximum power supplied from such sub-station shall not exceed 75 kilowatts without the written consent of the Board of Trade.

3. Where cast-iron street boxes are utilized as converting stations, each such station will contain one transformer only, of a power not exceeding 30,000 watts. Suitable high-pressure fuses will be enclosed in a second cast-iron case.

4. The cast-iron cases will be gas-tight and water-tight, the vacant spaces in the cases being restricted or filled up with suitable material to such an extent as to prevent any danger of explosion should any gas by accident obtain access.

5. Metallic portions (other than the conductors) of every transformer will be efficiently connected to earth. The iron street boxes will be electrically connected to the iron pipes containing the mains, or to the armouring of mains laid on the solid system, and will be provided with two separate covers or lids, the outer cover being separated from the box by non-conducting material, and being electrically connected to strips of metal laid immediately underneath the adjacent roadway or pavement, and the inner cover being electrically connected to the box.

6. Adequate provision will be made for the immediate escape of any gas or water from the street box. Every converting station will be examined at least twice in each week. Each transformer will be protected by a suitable automatic quick-acting cut-off.

7. From the converting stations a low-pressure supply at constant pressure will be given for the use of consumers. The low-pressure alternating current supply will be given at a constant pressure on the two or three wire system; in the latter case the intermediate conductor being, with the approval of the Board of Trade, connected with earth at one point only on each separate network, but insulated at all other points.

8. The high-pressure mains will, in some cases, be steel-armoured concentric cables, adequately insulated and drawn into iron pipes or

earthenware conduits, and in other cases they will be concentric paper-insulated, lead-covered, and laid in troughs filled in solid with composition. The outer conductor will be in all cases sufficiently insulated to withstand the full working pressure. The low-pressure mains will, in some cases, be similar cables, the insulation of both conductors being amply sufficient for the pressure to which they will be subjected. In other cases they will be triple concentric, or three-core, lead-sheathed, laid in troughs filled in solid with composition, and protected with strong tiles or cement. These mains will be laid directly in the ground.

9. For street lighting only the following systems will be used:—A supply of energy derived from the alternating generators used for general supply but transformed by means of a suitable rectifying apparatus into a high-pressure uni-directional constant current for the supply to arc lamps in series. The mains will be concentric or twin cables, adequately insulated and laid in cast-iron or earthenware pipes, or in troughs filled in solid with composition. The mains will be entirely separate from those laid for general supply. The arc lamps will all be connected to the inner conductor of the concentric mains, or on one conductor of a twin cable.

10. A supply of energy derived from alternating current generators used for general supply to arc lamps in parallel. The mains will be concentric cables adequately insulated and laid in the cast-iron pipes of the general supply system.

11. A supply of energy derived from alternating current generators used for general supply but transformed to the pressure required for the supply of arc lamps in series. The mains will be concentric or twin cables adequately insulated, and laid in cast-iron or earthenware pipes, or in troughs filled in solid with composition.

APPENDIX D

CONDITIONS OF APPROVAL REGARDING "EARTHING"

The outer conductor of all high-pressure mains, used for alternating currents, may only be earthed in accordance with the following conditions:—

1. That the high-pressure mains and any service lines in connection therewith be concentric throughout.

2. That the outer conductor in all cases forms a complete metal sheathing round the inner conductor.

3. That the connection with earth be made at one place only, and that the insulation of the electrical circuit be efficiently maintained at all other points (*see* definitions, "Earth.")

4. That the connections be such that the outer conductor of every high-pressure main be connected to earth (*see* definitions, "Earth.")

5. That the inner conductor of every high-pressure main and all conductors in connection therewith be properly protected and guarded at the generating station, and at every converting station and transformer.

Where the outer of a h.t. concentric is earthed the following regulations, in those issued by the Board of Trade, do not apply :—

> Regarding weekly insulation tests.
> Regarding means for indicating leakages.
> Regarding automatic cut-offs (in case of "outer").

The approval in this form does not authorize any connection with earth of any part of a circuit in which the current is uni-directional or rectified.

The intermediate or neutral conductor of three-wire systems of mains may only be earthed on the following conditions :—

1. The neutral conductor on each separate network to be earthed at one point only, this conductor being thoroughly insulated at all other points.

2. The system of distributing mains will be separated into special sections corresponding approximately to the different feeders, and these sections will be inter-connected only through suitable links or fuses arranged so as to be easily inspected and to be completely free from all risks of causing fire by defective action, arcing, &c.

3. The current from the neutral conductor to earth will be continuously recorded, and if it at any time exceed one-thousandth part of the maximum supply current, steps will be immediately taken to improve the insulation of the system.

It may be noted that the connection to earth should be made by duplicate cables and earthplates. A suitable arrangement is an earth connecting bar of large section connected by a $\frac{19}{16}$ cable or stranded bare conductor to a 3 ft. × 3 ft. earthplate imbedded in a load of coke buried well underground in damp, natural soil, and by another such conductor to the cast or wrought iron water service of a station or works, the connection to the latter being made in duplicate both by wrapping heavy copper tape round a cleaned length of the service and by bolting a tape under the joints, if of wrought iron, or fastening it to the pipe by two $\frac{1}{2}$-inch set screws, if of cast iron. The connection may be supplemented

by connecting together all cables to be earthed, the principals of the building, stanchions, &c., the water services, and the engines; the large area exposed being the most important safeguard in this respect.

APPENDIX E

SUMMARY OF REQUIREMENTS OF BOARD OF TRADE REGULATIONS

The form of regulations for securing the safety of the public, and for insuring a proper and sufficient supply of electrical energy which has been in force for many years was settled by a joint conference of undertakers and officials of the Board in 1895. Certain modifications have recently been made in the details of these regulations, but in their broad principles they remain as they were at the time of issue of the first edition of this work. It will be noted that the Home Office by the Factory and Workshops Act of 1901 are now also authorized to issue regulations respecting generating and sub-stations.

a. Prior to commencement of supply note that—

1. The sectional area of any conductor must not be less than 100 circular mils. (A 4.)

2. Each wire of a strand must not be less than No. 20 S.W.G.

3. The load on a high-pressure conductor must not exceed 500 k.w. (A 11), and automatic quick-acting cut-offs must be provided to ensure this (A 6 and A 8.) The latter portion of the regulation does not apply to any portion of the circuit which is earthed.

4. The arrangement must be such that in case of stoppage of supply not more than 200 k.w. are cut off, or more than eighty consumers affected. (B 3.)

5. All armouring or sheathing of cables, metallic cases of transformers, and all conduits, &c., must be earthed (A 10, A 15), and means must be taken to guard against charging adjacent masses. (A 16.)

6. Earthing devices must protect secondary circuit (A 9), if not earthed at any point.

7. Means must be taken to guard against lightning where necessary. (A 12.)

8. Means must be taken to prevent accumulation of gas in conduits and boxes (A. 14), and these must be regularly inspected.

9. Bare copper systems must be protected against accumulation of water. (A 17.)

10. High-pressure conductors above ground or in subways must be embedded in masonry or laid in earthed metal casing. (A 18, A 29.)

11. Maximum capacity of street tank transformers, 30 k.w., or underground sub-stations 75 k.w., except by special permission. (A 23.)

12. Fuses must be inserted in consumer's service lines. (A 27.)

13. Street boxes must be secured so that they cannot be opened except by means of a special appliance.

b. Tests specified.

Prior to commencing supply on cables, &c.—

1. Insulation resistance to be taken, with 50 per cent. greater than working pressure, and no less than 200 volts (A 8). (Record in Mains Test Book).

2. Insulation to be stressed to double-working pressure for half an hour (A 7). For plant 50 per cent. over working pressure. (Record in Mains Test Book.)

3. High-pressure lines must be completed before being brought into use. (A 20.)

Prior to connecting consumer's wiring—

4. Insulation test to be taken, leakage not to exceed $\frac{\text{supply current}}{10{,}000}$ (A 21). Insulation resistance required $=10{,}000\,\frac{V}{C}$ ohms, where V is pressure of supply and C the *maximum* supply current.

During use—

1. The total leakage from every complete circuit including apparatus must not exceed $\frac{\text{supply current}}{1{,}000}$ (A 6). Not applicable to earthed circuits.

2. Means must be provided to immediately indicate and locate leakages. (A 6.)

3. Insulation resistance of each circuit (where not earthed) to be measured weekly. (Record in Mains Test Book.) (A 6.)

This last test should always be taken if possible. In the case of single cables, or concentric where both poles can be insulated, there is no difficulty, but when earthed outer concentrics are in use it is obvious that tests of this kind cannot be made.

4. Ascertain that consumers' meters and fuses are in safe condition (A 24), and that wiring in places of public resort is maintained in efficient condition. (A 26.)

c. Requirements regarding supply.

1. The supply pressure must not exceed 250 volts at any pair of consumers' terminals (A 1), (except for special purposes when it may be given up to medium pressure upon special conditions. See Appendix I.).

2. The variations of pressure at the consumers' terminals must not exceed 4 per cent. from the declared constant pressure. (See D 8.)

3. The variation of frequency on alternating supply must not exceed 2½ per cent. (See D 9.)

4. Where three-wire service is brought in the supply must be given to two pairs of terminals, and wires from these must be kept distinct. (A 2.)

d. Notices prescribed by Board of Trade Regulations.

1. To Board of Trade, of any accident. (A 13.)
2. To gas company, of leakages of gas. (A 34*d*.)
3. To consumer, of defective insulation of wiring. (A 41.)
4. To public, of duration of discontinuance of supply. (B 2.)
5. To consumer, of stoppage of supply. (B 3.)
6. To consumer, of constant pressure at his terminals. (B 4.)
7. To consumers on alternating supply, of frequency. (B 5.)

e. Bulk supply.

1. Supply at high pressure may be given under special conditions issued in each case.

2. Supply at extra high pressure may be given subject to special conditions to a factory, mine, or electric traction works, and in the first two cases the provisions of the Factory Acts and the Mines Regulation Acts must be complied with. (A 3.)

APPENDIX F

RECOMMENDATIONS BY HOME OFFICE REGARDING ELECTRICAL GENERATING WORKS.

(*Summary, compiled from "Second Interim Report" of Departmental Committee.*)

WHERE direct current is generated at above 700 volts or alternating current above 350 volts:

1. The frames and bed-plates of generators and metal transformer

boxes shall be efficiently earthed, and all permanent metallic parts in transformer chambers shall be connected together and to earth.

2. Fencing rails shall be made of non-conducting material.

3. Switches, fuses, terminals, brushes, &c., shall be guarded from accidental contact, or the floor shall be covered with an insulating mat. High-pressure connections in transformer chambers shall be so protected that it is impossible to touch them.

4. Lubricating vessels, dollies or wipers shall be provided with an insulating handle.

5. Indiarubber gloves, supplied by the employer, shall be worn by persons working upon cables under high pressure, and managers shall see that they are in good condition and made use of.

6. The backs of switchboards shall have a clear space of 4 feet, and this space shall be kept closed. No persons except skilled electricians or men under such *personal and immediate supervision* shall be allowed to make repairs on switchboards, mains, machines, or other apparatus under high pressure, and all parts not necessarily exposed shall be kept covered to prevent accidental contact.

7. Switches shall be locked and kept locked by a responsible person when repairs are being effected upon the mains supplied by them.

8. Overhead conductors shall be insulated and efficiently supported, and shall not come within reach of persons passing by.

9. Holes through which high-pressure conductors pass shall be bushed with non-conducting material.

10. Switches which can be operated from the outside for cutting off both the high-pressure and low-pressure connections shall be fitted in all transformer chambers.

11. Series arc lamps shall be provided with means for completely disconnecting them from the mains, without disturbing the action of the other lamps.

12. All persons engaged in electrical works shall be made fully aware of the dangerous parts of the machinery, cables, and connections, and shall be practically instructed in methods of artificial respiration, and rules for artificial respiration shall at all times be kept affixed in the station.

13. All accidents occurring in generating stations or transformer chambers shall be notified according to the provisions of the Factory and Workshops Act.

APPENDIX G

UNDERGROUND SUB-STATIONS

IN April, 1904, the Home Office issued a memorandum of recommendations applying to sub-stations which a man can enter. These premises are subject to the general provisions of the Factory Act, 1901, in addition to any conditions imposed by the Board of Trade. By this Act the Home Secretary has power to make regulations for the safety of persons employed to attend to sub-stations, and the premises are now inspected by the Factory Department of the Home Office. The general recommendations for the construction of such chambers are:—

Height.—This should not be less than 7 ft., measured to the spring of the arch if an arched roof be used, or the same clear distance if flat.

Switch-boards.—The low-pressure should not be opposite to the high-pressure board, and these boards should be kept apart, and not be over the transformers unless these are below the floor and guarded. High-pressure apparatus and leads should be painted red and guarded against accidental contact.

Size.—Not less than 4 ft. square for single transformers. For capacities above 30 k.w., the chamber should be designed for 75 k.w., and in this case there should be a minimum width of 5 ft. and a minimum area of 50 sq. ft., say if square a cube of 7 ft., excluding entrance, for which 3 ft. by 3 ft. extra should be allowed.

Above 75 k.w. 5 sq. ft. extra should be allowed for every 10 k.w. additional capacity.

Entrance.—This should be at the end of side of the chamber. Entrance through the roof is objectionable, as, if any water enters, it is liable to wet the floor; a vertical ladder obstructs the space, and a person descending is brought very close to live conductors.

Double-floor Chambers.—These should have a depth of 6 ft. below the floor for the transformers and a height of 7 ft. above for working. The transformers being placed on the lower floor with working floor above, all switch gear being placed above the working floor.

Construction.—Chambers should be water-tight and glass pavement light avoided. The floor should be laid with incline of 1 in 100 towards a sump hole in entrance portion below the manhole. From this sump the water should be pumped or baled out, and no attempt should be made to drain it out gravitationally.

Ventilation.—This is required to enable work to be done by attendants without discomfort, in order to keep the temperature low, and to enable moisture to be carried off. Two ducts should be provided, one inlet and

one outlet, the latter near roof, and inlet near floor. In case of defective ventilation an electric fan is necessary. The ducts should be 1 sq., in. in area per 10 cubic ft. capacity of chamber, i.e. 75 k.w. chamber, 7 in. diameter ducts. Ducts should be carried above ground level, and precautions taken against rain water entering, while the mouths should not be immediately over transformers or switch-gear.

Manholes.—These should not be less than 2 ft. square. The cover when open should be locked back, and a grating easily opened from inside, to protect the opening when cover is up. The ladder should be one with flat treads, and at an angle to the wall. A door and stairway should be provided for chambers frequently visited, or over 300 k.w. capacity.

Space.—All passages and working spaces should be kept clear. A clear space of at least 3 ft. should be provided in front of switch-gear, and also at the back if there are cable connections to be examined behind.

Transformers.—The metallic portion of transformers and all metal in the chamber not in connection with the circuits should be efficiently earthed.

Connections.—These should be secured by lock nuts if nuts are used.

Telephone.—A telephone to the generating station should be provided.

Fuses.—These should be of the switch-fuse type.

Insulating Mats.—Rubber mats should be provided, and these be kept dry.

Inspection.—Care should be taken that supply is cut off before work is started on any main, &c., and that no duplicate connection can charge same, also that there can be no transforming up from low-pressure side.

APPENDIX H

ESTIMATION OF CONSUMPTION DURING STOPPAGE OF METER REGISTRATION

APPLICATION forms generally contain as one of the general conditions of supply, something in the nature of the following:—

"Should a supply be given before a meter is connected up, or should the meter from any cause cease or omit to register accurately the quantity of electricity used, the consumer will pay for current supplied for and during such period a reasonable proportion based on the average

former or subsequent reading of his meter, such proportion to be determined by the engineer, whose decision shall be final and binding on the consumer."

Estimations should be made upon the following general principles :—

(*a*) A curve should be prepared showing the general rates of units consumed per month, and any variation should be corrected in accordance with the figures given in a table derived from it.

(*b*) A similar period to that in which the meter is out of order, or has failed to register, should be taken for the purpose of calculating the average ascertained consumption.

(*c*) The estimation should be made by multiplying the number of days during which consumption was not registered, by the average daily ascertained consumption during another similar period when the meter was registering. The characteristics of the supply during the several periods should be identical in the following particulars :—

1. Maximum demand.
2. Epoch (or distance in time which separates each period from the longest or shortest day in the year) and
2. (Approximately) equal durations of time must be included in each period taken.

(*d*) If creepage has been taking place, the allowance for creepage should be made before estimating the consumption.

Creepage is found by :—

Tested daily creepage × number of days in period.

(*e*) If the maximum demand has varied, the estimation should be increased or decreased in proportion to the ratio of initial and altered demands.

(*f*) Should the epoch be different, then the estimation must be corrected by the ratio of the—

$$\text{I.}\quad \frac{\text{Units per month in registered period,}}{\text{Units per month in unregistered period;}}$$

or,

$$\text{II.}\quad \frac{\text{Units per month in unregistered period,}}{\text{Units per month in registered period.}}$$

In the event of the registered period having longer lighting hours (i.e. nearer December 21st in any year) than the unregistered, ratio II. must be used, and if conversely, then ratio I. must be taken.

(*g*) All estimations should be made out and full working figures shown on a form provided for the purpose.

APPENDIX I

BULK SUPPLY

Bulk supply may be given in several ways, of which the more important are the following :—

I. *To Authorised Undertakers.*

(*a*) To sub-stations consisting of premises in the joint occupation of the undertakers and of authorized distributors (i.e. companies or local authorities having Acts or Provisional Orders). Parts of these premises containing extra high-pressure rotary transformers or motor generators the property of the power company and placed in a part of the premises accessible only to the power company.

(*b*) Sub-stations consisting of premises in the joint occupation of the undertakers and of authorized distributors containing extra high-pressure transformers, rotary converters, or motor generators, the property of the power company, and accessible to the authorized distributors.

(*c*) Sub-stations consisting of premises in the sole occupation of authorized distributors to which an extra high-pressure supply, controlled by a fuse or circuit breaker, or switch, solely accessible to the power company, is given to transformers, converters, or motor generators, the property of, and worked by authorized distributors.

II. *To Consumers.*

(*a*) To sub-stations for general supply to consumers in the neighbourhood at high or low pressure, consisting of premises in the sole occupation of the power company.

(*b*) To sub-stations consisting of parts of premises, of a factory, &c., but such parts solely occupied by power company.

(*c*) To such stations on and solely for supply to a factory, such parts occupied by power company, but consumers having means of shutting off extra high-pressure supply.

(*d*) Direct supply at extra high pressure to large motors, under control of owners of a factory (special sanction required from Board of Trade and Home Office).

APPENDIX J

RULES REGARDING SUPPLY ABOVE 250 VOLTS

Where a supply at above 250 volts is required by consumers, as is the

case with motive power taken from the outers of a three-wire system, the Board of Trade consent under specified conditions, of which the following is an example:—

1. That the frame and shaft of every electric motor intended to be worked at the pressure specified in the approval shall be efficiently connected to earth.
2. That the supply to every motor shall be controlled by means of an efficient cut-off switch, placed in such a position as to be easily handled by the person in charge of the motor, and connected so that by its means all pressure can be cut off from the motor itself and from any regulating switch, resistance or other device in connection therewith.
3. That efficient fuses or other automatic cut-outs shall be provided, so as to protect the branch circuit on each side of each motor from excess of current. The above-mentioned switches and cut-outs shall be so enclosed and protected, that there shall be no danger of any shock being obtained in the ordinary handling thereof, or of any fire being caused by their normal or abnormal action.
4. That a notice shall be fixed in a conspicuous position at every motor and switchboard connected with the special supply, forbidding unauthorized persons to touch the motors or apparatus.
5. That the cable shall have a minimum insulation resistance of 2,500 megolems per mile.
6. That the switches and fuses shall be enclosed in stout metal cases connected to earth.
7. That it must not be necessary to open the cases to operate the switch.
8. That the circuits shall be so disposed that a person cannot simultaneously touch a point of each of the conductors.

APPENDIX K

PARTICULARS REQUIRED REGARDING MAINS

UNDER the Acts, local authorities and the Postal Telegraph Department are entitled to plans of mains and to such additional information as they may require. The following schedule contains the particulars which are asked for, and it is customary to fill up a printed form with these details and submit same with the plans intimating intention to extend the mains.

1. Street or road in which extensions are proposed.
2. Position, carriage-way or foot-way, and side of street or road. Distance from kerb.
3. Space occupied vertically and horizontally; diameter of pipe or size of troughing.
4. Depth, usually 14 in. clear under foot-ways, 18 in. under foot-way crossings and 24 in. under carriage-ways as minimum.
5. Position and size of chambers or boxes.
6. Voltage, maximum current capacity of mains, number of phases and frequency.
7. Type of cable, Single, double concentric, triple concentric, twin, or three-core.
8. Insulating material. India-rubber, fibre, or paper, &c.
9. Armouring or sheathing. Lead-sheathed, steel-tape armoured, &c.
10. External protection, laid direct in ground, drawn into cast-iron or earthenware pipes, laid solid in cast-iron or earthenware troughs filled in solid with bitumen or pitch and covered with tiles 1½ in. thick.
11. Clearance. Minimum of say 6 in. allowed between electricity mains and sewers, drains or telegraph pipes.
12. Special precautions. York stone flag at least 2 in. thick or concrete 3 in. thick interposed between telegraph pipes and electricity mains, at crossings, extending 6 in. laterally on every side of crossings.
13. Earthing, which wire, where, and disposition in cable: armouring or sheathing earthed at each box on the line by connection to the metallic case or such box.

The telegraph authorities approve of the works proposed subject to certain conditions, often in the following form:—

1. That not less than 48 hours before any work is begun, the undertakers give notice to the superintending engineer of the district, and that special attention be called to any work to be done between 6 p.m. and 6 a.m.
2. That fresh notices and plans in respect to any of the works not executed within twelve months be furnished.
3. That drawings of all manholes or surface boxes be furnished before proceeding with the works.
4. That within one month from the completion of various portions of the works, plans be furnished showing the high and low tension mains by continuous and dotted lines respectively. The plans to be tracings on cloth or photo prints mounted on calico, drawn to

the scale of 10 ft. to the mile, and showing the depths of the mains and variations thereof by figures written within a circle, and showing the position of the mains with regard to the kerb and to adjoining property by plain figures, not written in a circle, giving the number of the house or shop where such variations occur.

5. That statutory notices of one month be given for all future works, except mere service lines, the 48 hours' notices being required in all cases.

APPENDIX L

STANDARDS PROPOSED BY THE ENGINEERING STANDARDS COMMITTEE

A COMMITTEE appointed by the various engineering institutions has been at work for some time upon the preparation of tables of standards recommended for general acceptance in British engineering practice. The recommendations with regard to electrical engineering topics are given below :—Ten per cent. variation permissible on either side.

1. *Pressures, &c.*—Alternating and direct low pressure 110 v., 220 v., 440 v., 500 v.

Three-phase with neutral wire 380 v., between principal conductors giving 220 v. between any one and neutral.

Alternating high pressure, at generator 2,200 v., 3,300 v., 6,600 v., 11,000 v., shall give sine E.M.F. curve and excite at 65, 110, or 220 v. The regulation of an alternator shall be defined as the difference between the rated full-load pressure and the no-load pressure with the same speed and excitation. This difference expressed as a percentage of the rated full-load pressure shall be termed the percentage "pressure rise" of the alternator. They shall not have a greater percentage pressure rise than 6 per cent. on a non-inductive load and 20 per cent. on an inductive load, the latter being here considered as one having a power-factor of 0·8.

Primary alternating transformers 2,000 v., 3,000 v., 6,000 v., 10,000 v.

Secondary alternating transformers (no load) 115 v., 230 v., 460 v., 525 v.

Tramways, at motor 500 v.

2. *Frequency.*—50 periods and 25 periods.
3. *Rating of generators and motors.*—Six hours for continuous working, one hour for intermittent working.

Output and full-load speed at normal working temperature at end of run as given above.

Generators capacity in kilowatts : motors in brake horse-power.

Kw. or b.h.-p. volts and rev. per min. to be given for generators and motors, and in addition for alternators. excitation, volts and amps., frequency and power factor of output stated as load; for alternating motors in addition frequency and power-factor.

List Numbers and Speeds of Different Current Generators (up to 100 kw.)

List number. Kw.	Standard motor carcase.	Revs. per min.	List number. Kw.	Standard motor carcase.	Revs. per min.
6	7½	1,075	32	40	750
8	10	1,000	40	50	675
12	15	900	60	75	625
16	20	850	80	100	575
24	30	800	100	...	500

British standard generators of 100 kw. and above, whether for direct or alternating-current work, shall conform to the following list of sizes and speeds recommended for generators to be directly coupled to steam or gas engines :—

Kw.	Revolutions per minute.		
	Slow.	Medium.	High.
100	...	250	500
150	...	250	428
200	...	250	375
250	...	250	375
300	94	214	375
400	94	214	375
500	83	214	300
750	83	188	250
1,000	83	188	250

4. *Classification of Motors.*—Motors shall be rated Open, Protected,

Ventilated, Totally enclosed. A protected motor is a motor in which the armature, field coils, &c., are protected mechanically. A ventilated motor is a motor in which access to the armature, field coils, &c., is only obtained by opening a door, or removing a portion of the case.

No-Load Speeds Direct-Current Motors.

List No. B.h.-p.	Revs. per min. at full load.	List No. B.h.-p	Revs. per min. at full load.	List No. B.h.-p.	Revs. per min. at full load.
¼	1,600	5	1,000	30	750
½	1,400	7½	1,000	40	700
1	1,400	10	900	50	650
2	1,100	15	850	75	600
3	1,100	20	800	100	550

Alternating-current Induction Motors.

Single-phase 50 ∿.

List No. B.h.-p.	Revs. per min. at full load.	List No. B.h.-p.	Revs. per min. at full load.	List No B.h.-p.	Revs. per min at full load
1	1,500	7½	1,500	15	1,000
2	1,500	7½A	1,000	20	1,000
3	1,500	10	1,500	25	750
5	1,500	10A	1,000	...	...

Two and Three Phase, 50 ∿.

List No. B.h.-p.	Revs. per min. at full load.	List No. B.h.-p.	Revs. per min. at full load.	List No. B.h.-p.	Revs. per min. at full load.
1	1,500	10	1,500	40	750
2	1,500	10A	1,000	50	750
3	1,500	15	1,000	50A	600
5	1,500	20	1,000	75	600
7½	1,500	25	750	100	500
7½A	1,000	30	750	...	...

The figures referring to alternating-current motors give the no-load or synchronous speeds; allowance should, therefore, be made for a reduction in speed at full load of from about 7½ per cent. in the smallest motors to 2½ per cent. in the largest motors.

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